ASSESSMENT OF GREYWATER TREATMENT METHODS FOR REUSE IN ADDIS ABABA CONDOMINIUMS - A CASE OF SUMMIT CONDOMINIUM

NATNAEL AFEWORK ANDARGE

MASTER OF SCIENCE

ADDIS ABABA SCIENCE AND TECHNOLOGY UNIVERSITY

JANUARY 2019

ASSESSMENT OF GREYWATER TREATMENT METHODS FOR REUSE IN ADDIS ABABA CONDOMINIUMS - A CASE OF SUMMIT CONDOMINIUM

By

NATNAEL AFEWORK ANDARGE

A Thesis Submitted to

The Department of Environmental Engineering for the Partial Fulfillment of the

Requirements for the Master of Science in Environmental Engineering

ADDIS ABABA SCIENCE AND TECHNOLOGY UNIVERSITY

JANUARY 2019

Declaration

I hereby declare that this thesis entitled “Assessment of Greywater Treatment Methods For Reuse in Addis Ababa Condominiums - A Case of Summit Condominium**”** was composed by myself, with the guidance of my advisor, that the work contained herein is my own except where explicitly stated otherwise in the text, and that this work has not been submitted, in whole or in part, for any other degree or processional qualification.

Name	Signature, Date
______________	____________________

Certificate

This is to certify that the thesis prepared by Mr. Natnael Afework Anadarge entitled "Assessment of Greywater Treatment Methods For Reuse in Addis Ababa Condominiums - A Case of Summit Condominium" and submitted in fulfillment of the requirements for the Degree of Master of Science complies with the regulations of the University and meets the accepted standards with respect to originality and quality.

Singed by Examining Board:

External Examiner	Signature	Date:
_______________	_______________	_____________
Internal Examiner	Signature	Date:
_______________	_______________	_____________
Thesis Advisor	Signature	Date:
_______________	_______________	_____________

Dedicated to my beloved mother,

Muluken Bayu, May she rest in peace!

Abstract

Living in Addis Ababa is becoming harder every single day because of the increasing population of the city and the lack of basic necessities for the growing population's basic demands such as water.

If we take a look at the current data, Addis Ababa Water and Sewage Authority is capable of providing only about 525,000 m^3/day. However, the current estimated water demand of the city is about 930,415 m^3/day. (AAWSA, 2019) With the population growing every day and around 850,000 additional low cost mass housings to be built the near future and no new dams or big wells being constructed as water supply source, the task seems very hard for the government to solve the current and the future water shortage problem in a short time.

Therefore with such a big problem on hand an alternative water conservation method like greywater recycling must be considered, on this study entitled “Assessment of Greywater Treatment Methods For Reuse in Addis Ababa Condominiums” a case study site was selected and different treatment methods were assessed using MCA method using 6 governing factors to select the feasible treatment method for treating the greywater and use the treated water as a toilet flushing water and which will also suit the site area and the result showed that MBR and PGTS treatment methods came on top of the assessment.

Then a system design was conducted which includes the collection, treatment and distribution of the greywater and MBR method was used as the treatment option on the system design. Then a lab-scale treatment method was chosen from PGTS methods and a lab scale 4 barrel treatment of the greywater was conducted. All laboratory testing were done by APHA standards and they were used to characterize the greywater coming from the selected condo and the treated greywater results.

After the system and the lab-scale treatment was designed, it was concluded that using MBR and PGTS treatment methods in condominiums for treating the greywater and reuse it as toilet flushing water can have the potential of saving around 30% of total fresh water supply.

Acknowledgments

First, I would like to thank the Almighty GOD for giving me the patience and strength to successfully complete this thesis work. Next, I would like to express my genuine and heartfelt gratitude to my advisor, Dr. Abebe Worku for his professional guidance, supervision and assistance starting from proposal writing to end of the work.

I would also like to offer my sincere gratitude to Ms. Sosina Natnael a member of Sumit Condominium, for her positive and consistence help throughout my thesis work and AASTU chemistry lab technician Mr. Assefa Bedilu for his amazing assistance on the work. My thanks also go to all the Engineers and experts working in AAWSA and AAHCPO who have helped me a lot in accomplishing my task.

Finally, I would like to thank my mother for being the greatest mother and for raising me with love until her last breath, I also want to thank my father, friends and my work colleagues, who provided me all the helpful advices and supports during this thesis work.

Table of contents

List of tables

List of figures

Abbreviation and Acronyms

AAHCPO	Addis Ababa Housing Construction Project Office
AAWSA	Addis Ababa Water and Sewerage Authority
AWA	Australian Water Association
AWWA	American Water Works Association
BW	Black Water
CPUT	Cape Peninsula University of Technology
CSA	Central Statistical Agency
E.C	Ethiopian Calendar
EPA	Environmental Protection Agency (Ethiopia)
ETB	Ethiopian Birr
EU	European Union
G.C	Gregorian Calendar
GW	Greywater
HCPO	Housing Construction Project Office
Hhs	Households
MBR	Membrane bio reactor
MCA	Multi-Criteria Analysis
MDGs	Millennium Development Goals
MoWE	Ministry of Water and Energy
NGO	Non-Government Organization
PW	Potable Water
PGTS	Personalized greywater treatment systems
UN	United Nations
UNDP	United Nations Development Program
UN-HABITAT	United Nations Human Settlement Program
USEPA	United States Environmental protection Agency
WDM	Water Demand Management

List of Symbols

%	Percent
Km	Kilometer
Lcd/lpcd	Liters per capita per day/ liters per person per day
m	Meter
m^2	Square meter
m^3	Cubic meter
No	Number
^{o}	Degree
^{o}C	Degree Celsius
~	Approximately

CHAPTER 1

1. Introduction

1.1 Background to the study and motivation

The obstacles of ensuring a sustainable water supply in the world, has led to many researches on a variety of water conservation efforts. As population growth drives urbanization and fresh water demand to grow, new techniques for water preservation are being widely studied. One water conservation focus area of particular interest is household greywater reuse. The potential for reducing household water demand and therefore protecting the fresh water supply by reusing greywater is rapidly becoming more widely accepted.

Even though renewable, water is a finite resource, distributed unevenly in time and space. This distribution is increasingly more severe in arid communities where the net fresh water resources available reduces annually and increased urbanization and development has led to an overall increase in water demand. This water demand has traditionally been met with water from the best available sources. However, over the years, it has become evident that high quality water sources in many parts of the world are inadequate to meet demands and, that not all uses require the same water quality (A. A. Ilemobed, 2012). Some water uses can be supplied with water of an inferior quality, which frees the high quality sources for higher quality uses. This is nothing new in the history of mankind since by 226 A.D, Rome had eleven aqueducts and each one had its own quality of water and specific use (Duncan, 2002).

Many countries in both the developed and developing world face significant problems in maintaining reliable water supplies, and this is expected to continue in future years due in part to the impacts of global climate change. Growing populations will further increase the demand for water, and there are limited cost-effective water supply augmentation options (A. A. Ilemobed, 2012).

From the world's population, more than 1 billion people lack access to clean water, most of whom live in Africa and Asia, In consideration of the severity of the problem, the United Nations (UN) initiated the Millennium Development Goals (MDGs) action plan in the year 2000. One of the MDGs targets is, to reduce by half in 2015 the number of people who have no access to clean water but still 780 million people lack access to clean drinking water currently (UN-HABITAT, 2018)

Ethiopia has many water resources but the available water is not distributed evenly across the country and the amount varies with seasons and years. The problem in the country's situation is to maintain a year-round supply that is adequate to meet people's needs. To ensure that supply meets demand the source of the water must be carefully chosen, taking into account present and future demand for water, and the costs. The cost of water supplies is heavily influenced by the distance of reliable water sources from towns. The challenge for many towns is finding nearby water sources. The case is true for Addis Ababa as well since there are no new dams or wells as a source of fresh water supply, the availability of water for the residents is dwindling from time to time, the scarcity of water is even harsher on residents who are living in condominiums because most of them are built on the border sides of the city and many of which are very far from the supply location and the other major reason is, they have a huge water demand due to the high number of population they reside. That is why the need to use alternative methods to minimize the shortage and one of those methods is reusing greywater.

According to (AAWSA, 2019) the major reasons for shortages of water in Addis Ababa are:

- ✓ Technical problems of the sub ground water pumps
- ✓ The dwindling ground water supply
- ✓ Failure in the water pipe lines
- ✓ Problems on quality of ground water

With such a big problem facing the city, looking at other alternative water sources like greywater will be a better option. Treating Greywater and reuse it by replacing scarce drinking water to meet some non-potable water demands such as flushing of toilets, firefighting and lawn irrigation is encouraged in several places due to one or more of the reasons below according to (A. A. Ilemobed, 2012)

A. The opportunity to provide reliable non-potable water services in locations where municipal drinking water supplies are limited or non-existent;
B. The potential to reduce the overburden on traditional drinking water sources by reducing urban drinking water demand by between 30-70% (Radcliffe, 2003);
C. The potential to reduce sewage discharges
D. Minimizing the rising costs of drinking water treatment by reducing the quantity of chemicals required to treat drinking water and in the reduction of sludge which arises during the treatment of drinking water.

Since this study focuses on the reuse of greywater to tackle the water shortage in an urban condominium(the reason why a condominium is chosen is elaborated below), it is reasonable to focus on the reuse of the greywater to be for toilet flushing water instead of firefighting or irrigation because, Addis Ababa don't have a well-designed pipe line system for firefighting and studying a greywater reuse for firefighting purpose is not feasible for a time being and since land in such a scarce resource in the city and there are no huge plantations in the city designing greywater for an irrigation purpose also seems not feasible, Therefore this study will deal with studying systems to reuse greywater for toilet flushing purpose in condominium specifically summit condominium block-349(the first block in a gated block of 4 buildings inside the summit site condominiums).

The main reason why a condominium was chosen for this study is because of the following reasons;

- Condominiums in Addis Ababa suffer highly from water shortage because there are no nearby neighborhoods to fetch water from during scarcity because most of them are built at the border lines of the city.
- Condominiums typically generate higher volume of greywater as compared to a single stand- alone household.
- Since the number population living on such housings is high, the demand of fresh water is also high which means the amount of fresh water which can be saved from the implementation of greywater recycling system is also significant compared to standalone houses.
- Condominiums are multi-story buildings with centralized service areas and hence, the installation of the greywater reuse system will likely be easier for plumbing to connect several households within a building than as comparison to several stand-alone households spread over large area.
- Compare to stand-alone houses condominiums are reasonably access-controlled and centrally managed and hence, potential risks to public health can be mitigated.

Internationally, greywater reuse for toilet flushing has been successfully implemented in several places, e.g. Palma Beach hotel, Spain (March, 2002); Florianopolis, Southern Brazil (Ghisi, 2007); Institute Agronomique et Veterinaire, Rabat, Morocco (El Hamouri, 2207); Berlin, Germany (E, 1999); Loughborough University (D, Greywater reclamation for non-potable reuse., 1998) and the Millennium Dome (Hills, 2201) United Kingdom; Annecy Residential Building, France (Lazarova, 2001); the Irvine Ranch Water District,; Taiwan (Chin-Jung, 2005); and Ottawa, Canada (Oasis Design, 2006). As they were shortly revised by (A. A. Ilemobed, 2012).

In contrast, some of the failures and controversies surrounding greywater reuse systems include long payback periods, outbreak of water-borne diseases due to greywater ingestion, clogging or fouling of filters, unpleasant odors, negative perceptions, and/or sediment/microbial accumulation in the storage tank.

Greywater reuse in Ethiopia is not commonly practiced. There are few projects in Arbamich, Jimma and Gonder, which were planned and executed by collaboration of the state universities and the city municipals and almost all of them are focused using greywater for irrigation purposes. Greywater is poured on top of the stones and filters slowly through the soil column. These systems were primarily designed for low cost, small-scale irrigation with greywater.

On this study dual water reticulation system is considered, dual water reticulation system comprises two sub-systems – a conventional system that meets potable end uses and a separate system that meets non-potable end uses within a building. The separate system comprises the components that collect, treat, store and supply greywater for toilet flushing. Dual grey and drinking water reticulation systems (henceforth, dual systems) are particularly promising for application in high-density urban buildings.

1.2 Statement of the problem

The rapidly growing population of Addis Ababa comes with a growing demand of basic necessities such as clean drinking water. And what the capital city of Ethiopia /Africa is experiencing right now on water supply is very alarming, this is due to the water demand for Addis Ababa is now greater than the water production capacity of the city and on the other hand the city government of Addis Ababa Housing Construction Project Office (AAHCPO) is in construction of condominium housing apartments in ten sub-cities in an effort to reduce the problem of housing in the city targeting 886,978 housing unit in 2020 E.C (AAHCPO, 2015) However, the availability of adequate and safe water supply is among the basic and essential elements in any housing development program.

Addis Ababa is currently getting water supply from surface water of Gefersa, Legedadi and Dire dams with additional supplies from ground water pumped from Akaki well fields and other wells and springs within the city. Surface water from Legedadi and Dire dam is treated at Legedadi water treatment plant which have a production capacity of 170,000m^3/day and the surface water from Gefersa dam is treated at Gefersa water treatment works having a production capacity of 30,000 m^3/day. Similarly, the collective groundwater production from Akaki well fields and other boreholes within and around the city is estimated as 325,000 m^3/day. Therefore, the total current water production is about 525,000 m^3/day. (AAWSA, 2019) However, the current estimated water demand of the city is about 930,415 m^3/day. (AAWSA, 2019)

With such a big problem at hand it is essential to reduce the water consumption of fresh water that is by substituting fresh water with alternative water resources and to optimize water use efficiency through reuse options. Among these alternatives greywater can be used to meet the existing deficit. Greywater is commonly defined as wastewater generated from shower, hand basins and cloth washing which accounts 40-50 % of the outflow from homes. Greywater must be treated before reuse, using a variety of treatment technologies depending on the desired quality for the intended reuse applications such as for toilet flushing, drinking, gardening, car washing, floor cleaning, etc. The greywater treatment processes can involve right from simple low-cost devices to highly complex and advanced biological treatment processes incorporating sedimentation tanks, bioreactors, filters, pumps and disinfection systems.

Therefore, the main purpose of this research is assess different methods of treatment and to design a water recycling method for greywater in order to reuse it for toilet flushing purpose, which accounts for 25-35% of total fresh water use in the households (AAWSA, 2019), therefore reusing the greywater for toilet flushing purpose can save up to 25-35% of the total fresh water demand in the households.

The research will focus on water quality parameters like BOD_5, TS, TSS, TDS, TVS, COD, DO in mg/l, PH and microbial content values of the greywater and a decentralized feasible treatment method to bring those parameters to the desired quality to meet toilet flushing water quality.

1.3 Research Questions

- ✓ What is a feasible greywater treatment method in order to reuse the greywater for toilet flushing purpose in Addis Ababa condominiums, specifically summit condominium?
- ✓ What is the opinion of the residents toward living in a proposed mass housing with a recycled greywater system?

1.4 Objectives of the study

1.4.1 General Objective

The main objective of this research is to assess and study feasible greywater reuse method out of the existing treatment methods and redesign it for the selected condominium that include collection, treatment and distribution method of greywater in order to reuse it for toilet water flushing purpose in Summit Condominium block-349.

1.4.2 Specific Objective

- ✓ Evaluate Household water demand, calculate the amount of greywater generation from the selected condominium block and characterize the greywater generated from the selected condominium block.
- ✓ Identify possible socio-technical issues on greywater reuse for toilet flushing purpose in the condominiums.
- ✓ Design the appropriate greywater collection treatment and distribution method fit for the water quality of toilet flushing.
- ✓ Run a lab-scale treatment technology assessment for the designed system.

1.5 Significance of the study

This study will help the reader to understand and consider an alternative solution to Addis Ababa's major problem in public mass housings, which is water and this study can also be presented to governmental and non-governmental organizations to further study this in details and run a sample construction in a single site by organizing a fund to finance it or it might help to spark a new studies which can give solutions to the huge fresh water scarcity in the city.

1.6 Scope of the study

This research will focus on finding feasible greywater reuse technique and designing a system for the selected condominium in order to use the treated greywater for toilet flushing purpose in a single block located in Summit Condominium. The study will compare existing mechanisms and create a system which will best suit the site status. Including a lab scale construction based on the outcome of the result.

CHAPTER 2

2. Literature review

2.1 Greywater Definition

Greywater, (sometimes spelled "graywater", "grey water", "gray water") gets its name from its cloudy appearance and from its status as being between fresh, potable water (known as "white water") and sewage water ("black water") is untreated wastewater resulting from lavatory wash basins, laundry and bathing. It does not contain wastewater from toilets, urinals or any industrial process. Wastewater from kitchen sinks is also often excluded because of the high food and grease content. Black water, which refers to toilet wastewater and kitchen wastewater, is a distinct wastewater stream in quality to greywater. As a result, greywater which at generation is a better quality resource than blackwater can be beneficially and appropriately employed for certain non-potable water requirements such as toilet flushing. (Eriksson E. K., 2002)

2.2 Residential water consumption

According to (A. A. Ilemobed, 2012) residential water consumption depends on several factors for example: The degree of aridity, Income, Level of development, Level of services, Household occupancy and Culture

Residential water consumption is typically measured as liters per person per day (l/p/d). Water consumption tends to increase with increasing income, decreasing household occupancy and increased level of development. In the UK, a water consumption range of 102 to 212 l/p/d was reported between 1991 and 1998 and it is around 149 l/p/d. This compares well with the values of 115-260 l/p/d (Griggs, 1997) presented for the rest of Europe about the same time but is lower in comparison to the 450 l/p/d published for Zurich, Switzerland (Ghisi, 2007).The water consumption figures for the USA about 2 decades before, appears to be within the range published in Table 1 for the UK. In 1998, a water consumption figure as high as 1136 l/p/d (which is likely to have included garden irrigation) was reported for some arid areas in the US (A. A. Ilemobed, 2012). Table below shows different water consumption rates in different countries as organized by (Laine, 2001).

Table 1: Domestic water consumption in l/p/d for different end uses in various Countries

Reference	(Butler, 1991)	(D S. , 1998)	(Mikkelsen, 1999)	(Van der Hoek, 1999)	(Laak, 1998)	(Ligman, 1974)	(Siegrist, 1976)
Country	**UK**	**UK**	**DENMARK**	**THE NETHERLANDS**	**USA**	**USA**	**USA**
TOILET	31	61.2	40	30.5	75	6	36
KITCHEN	13	29.7	20	10.5	14	13	18
WASH BASIN	13	25.5	-	5.4	8	-	-
BATH AND SHOWER	28	34.4	45	59.7	32	47	38
WASHING MACHINE	17	25.6	10	23.1	28	38	41
OTHER	-	35.9	45	15.4	-	6	-
TOTAL(l/p/d)	102	212.3	160	144.6	157	180	133

2.3 Benefits of Greywater Treatment

Recycling greywater not only reduces the consumption of water, it also reduces the volume of water discharged into the sewerage system. Consumers with water meters could therefore save money on both their water supply and wastewater bills. There are many ecological benefits of greywater recycling could be summarized as follows:

- ❖ **Lowering the fresh water use:** Greywater can replace fresh water in many instances, saving money and increasing the effective water supply in regions where irrigation is needed. Residential water use is almost evenly split between indoor and outdoor. All except toilet water could be recycled outdoors, achieving the same result with significantly less water diverted from nature.
- ❖ **Less strain on septic tank or treatment plant**: Greywater use greatly extends the useful life and capacity of septic systems. For municipal treatment system by decreasing the wastewater flow which in turn means higher treatment effectiveness and lower treatment cost.
- ❖ **Less energy and chemical use:** Less energy and chemicals are used due to the reduced amount of both freshwater and wastewater that needs pumping and treatment. For those providing their own water or electricity, the advantage of a reduced burden on the infrastructure is felt directly. Also, treating your wastewater in the soil under your own fruit trees definitely encourages you to dump fewer toxic chemicals down the drain.
- ❖ **Highly effective purification:** Greywater is purified to a spectacularly high degree in the upper, most biologically active region of the soil. This protects the quality of natural surface and ground waters.
- ❖ **Groundwater recharge:** Greywater application in excess of plant needs recharges groundwater.
- ❖ **Plant growth:** Greywater enables a landscape to flourish where water may not otherwise be available to support much plant growth.

2.3.1 Uses of Recycled Greywater

Greywater can be used untreated, or it can be treated to varying degrees to reduce nutrients and disease-causing microorganisms. The appropriate uses of greywater depend on both the source of greywater and the level of treatment. Recycled water is most commonly used for non-potable (not for drinking) purposes, such as agriculture, landscape, public parks, and golf course irrigation. Other non-potable applications include cooling water for power plants and oil refineries, industrial process water for such facilities as paper mills and carpet dyers, **toilet flushing**, dust control, construction activities, concrete mixing, and artificial lakes. (Program, 2015)

Although most water recycling projects have been developed to meet non-potable water demands, a number of projects use recycled water indirectly for potable purposes. These projects include recharging ground water aquifers and augmenting surface water reservoirs with recycled water. In ground water recharge projects, recycled water can be spread or injected into ground water aquifers to augment ground water supplies, and to prevent salt water intrusion in coastal areas.

The use of greywater at decentralized sites for landscape irrigation and toilet flushing reduces the amount of potable water distributed to these sites, the amount of fertilizer needed, and the amount of wastewater generated, transported, and treated at wastewater treatment facilities. In other words, water reuse saves water, energy, and money. (Program, 2015)

2.4 Greywater generation

The volume and pattern of greywater generated in a household varies and is influenced by factors such as total potable water consumption, water supply level of service, number of household members, and age distribution of household members, lifestyles, and water use pattern. (Al-Jayyousi, 2003)

Greywater volume in low-income areas of poor countries in Africa with water scarcity and rudimentary forms of water supply (e.g. community taps or wells) can be as low as single-digit volumes per person per day in households where surface water bodies (e.g. rivers or lakes) are used for personal hygiene. On the other hand, households in middle- to high-income areas with piped water reticulation may generate significant volumes per person per day. It is estimated that on average, typical greywater generation in Addis Ababa households with piped water reticulation may likely range between 40-60 l/p/d (approximately 50% of total water consumption). (AAWSA, 2019) figure below shows a typical residential end use of greywater.

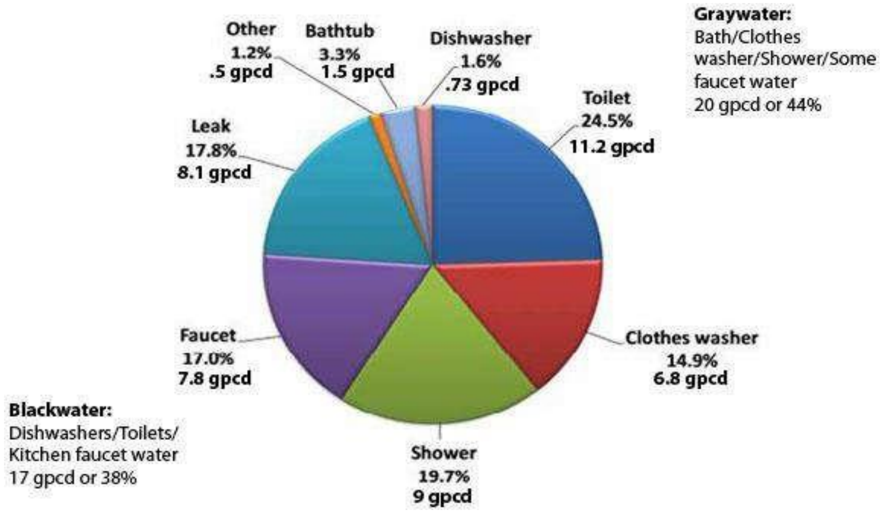


Figure 1: Residential End Use of greywater

On average the volume of water use in the house per day in Addis Ababa is 100-110 L/person/day (AAWSA, 2019). More than half of this water can be captured and recycled from the greywater. The different sources of greywater are classified and explained:

Bathroom greywater: (bath, basin and shower) contributes approximately 50% of the total greywater volume. Bathroom greywater can be contaminated with hair, soaps, shampoos, hair dyes, toothpaste, lint, nutrients, body fats, oils and cleaning products.

Laundry greywater: contributes approximately 30% of total greywater volume. Wastewater from the laundry varies in quality from wash water to rinse water to second rinse water. Laundry greywater can be contaminated with lint, oils, grease, laundry detergents, chemicals, soaps, nutrients and other compounds.

Kitchen wastewater: is sometimes considered as a greywater source. If a suitable treatment is not available, kitchen wastewater should not be used due to the amount of contaminants (food particles, oil, grease, etc.) it contains. Fortunately kitchen greywater contributes a relatively small portion of the total available greywater

2.5 Greywater characteristics

The characteristics of domestic greywater vary over time and space. Three factors significantly affect greywater composition: water supply quality, the condition of the components conveying greywater from point of discharge, and the water related activities in the house (Eriksson E. K., 2002). Table below indicates the likely constituents of water from various household sources.

Table 2: Common constituents of domestic greywater

(CSBE, 2003)

Water Source	Characteristics
Automatic Clothes Washer	Bleach, Foam, High pH, Hot water, Nitrate, Oil and Grease, Oxygen demand, Phosphate, Salinity, Soaps, Sodium, Suspended solids, and Turbidity
Automatic Dish Washer	Bacteria, Foam, Food particles, High pH, Hot water, Odor, Oil and grease, Organic matter, Oxygen demand, Salinity, Soaps, Suspended solids, and Turbidity
Bath tub and shower	Bacteria, Hair, Hot water, Odor, Oil and grease, Oxygen demand, Soaps, Suspended solids, and Turbidity
Sinks, including kitchen	Bacteria, Food particles, Hot water, Odor, Oil and grease, Organic matter, Oxygen demand, Soaps, Suspended solids, and Turbidity

As could be seen in Table 2, greywater contains oils, fats, detergents, soaps, nutrients, salts and particles of hair, food and lint, which can impact on operational performance and life of a greywater irrigation system. If these contaminants aren't managed correctly they can degrade soil structure, clog groundwater flow paths or even cause non wetting characteristics in garden soils. In addition, greywater can contain pathogenic microorganisms including bacteria, protozoa, viruses and parasites in concentrations high enough to present a health risk. Therefore, a level of caution must be exercised with greywater reuse. This can be achieved by not allowing unnecessary human contact with greywater, or by treating the greywater to remove or destroy the microorganisms.

Greywater quality will vary based on the end uses of water. For example, cooking habits as well as the amount and type of soaps and detergents will significantly determine the level of contamination in greywater. Table below will summarizes the typical characteristics of greywater according to various published literature articles.

Table 3: Characteristics of domestic greywater according to various published literature articles

Typical Greywater Characteristics						
Source						
		(Eriksson E. K., 2002)	(Asano, 1998)	(Gross, 2006)	(Christova-Boal, 1996)	(Tchobanoglous, 1991)
Parameter	Units	Residential laundry and bathroom greywater	Residential laundry and bathroom greywater	Residential laundry and bathroom greywater	Residential laundry and bathroom greywater	Untreated domestic waste water
COD	Mg/L	100-725	230-1340	702-984	--	250-800
BOD	Mg/L	76-380	173-462	280-688	48-290	110-400
Turbidity	NTU	28-1340	--	--	50-240	--
TSS	Mg/L	54-280	78-303	85-285	48-250	120-400
Total Nitrogen	Mg/L	5-21	--	25-45.2	1-40	20-85
Total Phosphorus	Mg/L	0.1-2	--	17.2-27	0.62-42	4-15
Total Coliform	CFU/100 ml	$56\text{-}2.4*10^3$	--	--	$500\text{-}2.4*10^7$	$10^6\text{-}10^9$
E.coil	CFU/100 ml	$100\text{-}2.82*10^7$	--	--	--	--

2.5.1 Physical characteristics

Temperature

Greywater temperature is often higher than that of the water supply and varies within a range of 18–30 ^oC. These rather high temperatures are attributed to the use of warm water for personal hygiene and discharge of cooking water. These temperatures are not critical for biological treatment processes (aerobic and anaerobic digestion occurs within a range of 15–50 ^oC, with an optimal range of 25–35 ^oC) (Tchobanoglous, 1991)On the other hand, higher temperatures can cause increased bacterial growth and decreased $CaCO_3$ solubility, causing precipitation in storage tanks or piping systems.

Suspended solids

Food, oil and soil particles from kitchen sinks, or hair and fibres from laundry can lead to high solids content in greywater. These particles and colloids cause turbidity in the water and may even result in physical clogging of pipes, pumps and filters used in treatment processes. Especially non-biodegradable fibers from clothing (polyester, nylon, polyethylene), powdered detergents and soaps, as well as colloids are the main reasons for physical clogging. Suspended solids concentrations in greywater range from 50–300 mg/l, but can be as high as 1,500 mg/l in isolated cases (D, Greywater reclamation for non-potable reuse., 1998) the highest concentrations of suspended solids are typically found in kitchen and laundry greywater. Suspended solids concentrations strongly depend on the amount of water used. Observations in Nepal, Malaysia, Israel, Vietnam, and the United States revealed average suspended solids loads of 10–30 g/p/d, contributing to 25–35% of the total daily suspended solids load in domestic wastewater, including toilet wastewater (Ledin et al., 2001).

Color and turbidity

These are also another physical characteristics of greywater, the color and turbidity of greywater tends to get darker and heavier as the more nutrients gets into the water then finally becomes black water.

2.5.2 Chemical characteristics

Greywater chemical parameters which are relevant to consider are:

- pH
- Alkalinity
- Electrical conductivity
- Sodium adsorption ratio (SAR)
- Biological and chemical oxygen demand (BOD5, COD)
- Nutrient content (nitrogen, phosphorous), and heavy metals, disinfectants, bleach, surfactants or organic pollutants in detergents.

pH

The pH indicates whether a liquid is acidic or basic. For easier treatment and to avoid negative impacts on soil or plumbing when reused, greywater should show a pH in the range of 6.5–8.4 (FAO, 1985) (USEPA, 2007) The pH value of greywater, which strongly depends on the pH value of the water supply, usually lies within this optimal range. However, (Christova-Boal, 1996) observed 9.3–10 pH values in laundry greywater, partly as a result of the sodium hydroxide-based soaps and bleach used. Greywater with high pH values alone are not problematic when applied as irrigation water, but the combination of high pH and high alkalinity, a measure of the water's ability to neutralize acidity, is of particular concern. Greywater alkalinity (indicated as CaCO3 concentrations) is usually within a range of 20–340 mg/l (Li, 2009), with highest levels observed in laundry and kitchen greywater.

Biological and chemical oxygen demand (BOD_5, COD)

The biological and chemical oxygen demand (BOD_5, COD) are parameters to measure the organic pollution in water. COD describes the amount of oxygen required to oxidize all organic matter found in greywater. BOD_5 describes biological oxidation through bacteria within a certain time span (normally 5 days (BOD_5). The main groups of organic substances found in wastewater comprise proteins (mainly from food), carbohydrates (such as sugar or cellulose), fats and oils as well as different synthetic organic molecules such as surfactants that are not easily biodegradable. Discharging greywater with high

BOD and COD concentrations into surface water results in oxygen depletion, which is then no longer available for aquatic life.

The BOD loads observed in greywater in different countries amount to 20–50 g/p/d (Friedler, Quality of individual domestic greywater streams and its implication, 2002) (Lin, 2005). BOD and COD concentrations in greywater strongly depend on the amount of water and products used in the household (especially detergents, soaps, oils and fats). Where water consumption is relatively low, BOD and COD concentrations are high. (Dallas, 2004) observed average BOD5 of 167 mg/l in mixed greywater in Costa Rica with a 107 l/p/d water consumption. In Palestine, where the greywater flow from comparable sources (bath, kitchen, laundry) attains only 40 l/p/d, average BOD was as high as 590 mg/l and exceeded 2,000 mg/l in isolated cases (Burnat, 2005)
The COD/BOD ratio is a good indicator of greywater biodegradability. A COD/BOD ratio below 2–2.5 indicates easily degradable wastewater. While greywater is generally considered easily biodegradable with BOD accounting for up to 90% of the ultimate oxygen demand (Del Porto, 2000), different studies indicate low greywater biodegradability with COD/BOD ratios of 2.9–3.6 (Al-Jayyousi, 2003) This is attributed to the fact that biodegradability of greywater depends primarily on the type of synthetic surfactants used in detergents and on the amount of oil and fat present. While Western countries have banned and replaced non-biodegradable and, thus, troublesome surfactants by biodegradable detergents (e.g. ABS replaced by LAS) (Tchobanoglous, 1991)such resistant products may still be used (e.g. in powdered laundry detergents) in low and middle-income countries. Greywater data collected in low and middle-income countries indicate COD/BOD ratios within a range of 1.6–2.9, with maximum rates in laundry and kitchen wastewater.

Nutrients (nitrogen, phosphorous)

Greywater normally contains low levels of nutrients compared to toilet wastewater. Nonetheless, nutrients such as nitrogen and phosphorous are important parameters given their fertilizing value for plants, their relevance for natural treatment processes and their potential negative impact on the aquatic environment. Especially the high phosphorous contents sometimes observed in greywater can lead to problems such as algae growth in receiving water. (Butler, 1991)

Levels of nitrogen in greywater are relatively low (urine being the main nitrogen contributor to domestic wastewater). Kitchen wastewater is the main source of nitrogen in domestic greywater, the lowest nitrogen levels are generally observed in bathroom and laundry greywater. Nitrogen in greywater originates from ammonia and ammonia-containing cleansing products as well as from proteins in meats, vegetables, protein containing shampoos, and other household products (Del Porto, 2000) In some special cases, even the water supply can be an important source of ammonium nitrogen. This was observed in Hanoi (Vietnam) where NH4-N concentrations as high as 25 mg/l were measured, originating from mineralization of peat, an abundant organic material in Hanoi's groundwater aquifers (Holt, 2003)Typical values of nitrogen in mixed household greywater are found within a range of 5–50 mg/l with extreme values of 76 mg/l, as observed by (Siegrist, 1976) in kitchen greywater.

In countries where phosphorous-containing detergents have not been banned, dishwashing and laundry detergents are the main sources of phosphorous in greywater. Average phosphorous concentrations are typically found within a range of 4–14 mg/l in regions where non-phosphorous detergents are used (Eriksson E. K., 2002) However, they can be as high as 45–280 mg/l in households where phosphorous detergents are utilized, as observed in Thailand (Stanner, 1995).

2.5.3 Microbiological characteristics

Greywater may pose a public health risk given its contamination with pathogens, e.g. viruses, bacteria, protozoa, and intestinal parasites. For light greywater, these pathogens are primarily faecal in origin (e.g. hand washing after toilet use, washing of babies after defecation, and diaper washing) while for dark greywater, these pathogens originate from both faecal and food (e.g. washing of vegetables and raw meat) contamination. Faecal contamination of greywater typically depends on the age distribution of household members, i.e. the higher faecal contamination of greywater is typically experienced where babies and young children are present in a household. (A. A. Ilemobed, 2012)

The often hesitance by the public and decision-makers to reuse greywater stems from the potential for human exposure which will lead to illness. Enteric viruses, which are known to be the most critical group of pathogens, can cause illness even at low doses and cannot be detected by routine microbial analysis. They also represent the microbial component that is most difficult to process: it can be assumed that a process effective in removing enteric viruses will be similarly effective for all other pathogens (Asano, 1998).

It is normal, however, to base standards on the more readily quantifiable indicator organisms of faecal or total coliforms since the main issue when reusing greywater is the potential risk to human health. These indicator species demonstrate a potential for disease transmission, rather than an actual risk of illness, but are more familiar bacteriological quality determinants than viruses and are more easily measured. On the other hand, no proven correlation exists between concentrations of indicator species and actual pathogen levels, and some pathogens are known to be more resistant to treatment than the indicator species (Asano, 1998)). This has resulted in the more conservative approach being adopted in the USA, Japan and Australia where greywater reuse is an established operation. In the USA specifically, the USEPA guideline for water recycling, (USEPA, 2007)promotes non-detectable concentrations of faecal coliform for urban reuse combined with a specification for a minimum level of treatment required (Jefferson, 2001)Greywater, which can contain at least 105/100 ml of potentially pathogenic microorganisms, typically changes in quality over time. Research has shown that counts of total coliform and faecal coliform increased from 100-l05/100 ml to above 105/100 ml within 48 hours in stored greywater from various sources (Al-Jayyousi, 2003). Easily bio-degradable organic compounds, which are typically found in dark greywater, also favor the growth of microorganisms (Ottoson, 2003)

2.5.4 Oil and grease (O&G)

Greywater may contain significant amounts of fat such as oil and grease (O&G) originating mainly from kitchen sinks and dishwashers (e.g. cooking grease, vegetable oil, food grease etc.). Important O&G concentrations can also be observed in bathroom and laundry greywater, with O&G concentrations ranging between 37 and 78 mg/l and 8 35 mg/l, respectively (Christova-Boal, 1996). The O&G content of kitchen greywater strongly depends on the cooking and disposal habits of the household. No data was found on O&G concentrations specific to kitchen greywater, but values as high as 230 mg/l were observed in Jordan for mixed greywater (Al-Jayyousi, 2003), while Crites and (Tchobanoglous, 1991) observed O&G concentrations ranging between 1,000 and 2,000 mg/l in restaurant wastewater. As soon as greywater cools down, grease and fat congeal and can cause mats on the surface of settling tanks, on the interior of pipes and other surfaces. This may cause a shutdown of treatment and disposal units such as infiltration trenches or irrigation fields. It is therefore important that O&G concentrations are maintained at acceptable levels (< 30 mg/l, (Tchobanoglous, 1991) to avoid problems with downstream treatment and disposal systems.

2.6 Greywater treatment methods

The quality of greywater between households, and even within households, varies daily depending on the activities of the house hold’s occupants. In addition, the quality of greywater varies depending on the source of the water as shown in the table 4 below. For most households greywater contains soap, shampoo, toothpaste, shaving cream, laundry detergents, hair, lint body oils, dirt, grease, fats, chemicals (from soap, shampoos, cosmetics) and urine. Greywater also contains bacteria, parasites and viruses washed from the body and clothes.

Considering the possible contents from greywater sources there are reasons why greywater may need to be treated, to remove substances that may be harmful to human health, plants, fixtures, to the environment and clog the irrigation system. The choice of the greywater treatment depends on the owner’s willingness to operate and maintain the facility; the source of greywater to be recycled; and the purpose of the greywater reuse whether for subsurface irrigation or sprinkler irrigation or for toilet flushing or waterfalls (WHO, 2006)

The different studies carried out concerning the greywater showed that all types of greywater have good biodegradability. Therefore, the treatment methods applied for greywater reuse included physical, chemical, and biological systems. Most of these methods are preceded by a solid-liquid separation step as pre-treatment and followed by a disinfection step as post treatment. To avoid the clogging of the subsequent treatment, the pre-treatments such as septic tank, filter bags, screen and filters are applied to reduce the amount of particles and oil & grease. The disinfection step is used to meet the microbiological requirements.

Table 4: common greywater treatment methodologies

Treatment Technique	Description	Advantages	Disadvantages
Sand filter	Beds of sand or in some cases coarse bark or mulch which trap and adsorb contaminants as greywater flows through.	Simple operation, low maintenance, low operation costs	High capital cost, reduces pathogens but does not eliminate them, subject to clogging and flooding if overloaded.
Membrane bioreactor	Uses aerobic biological treatment and filtration together to encourage consumption of organic contaminants and filtration of all pathogens	Highly effective if designed and operated properly, high degree of operations flexibility to accommodate greywater of varying qualities and quantities, allows treated water to be stored indefinitely.	High capital cost, high operating cost, complex operational requirements.

Activated carbon filter	Activated carbon has been treated with oxygen to open up millions of tiny pores between the carbon atoms. These filters thus are widely used to adsorb odorous or colored substances from gases or liquids.	Simple operation, activated carbon is particularly good at trapping organic chemicals, as well as inorganic compounds like chlorine.	High capital cost, many other chemicals are not attracted to carbon at all -- sodium, nitrates, etc. This means that an activated carbon filter will only remove certain impurities. It also means that, once all of the bonding sites are filled, an activated carbon filter stops working.
Disinfection	Chlorine, ozone, or Ultraviolet light can all be used to disinfect greywater.	Highly effective in killing bacteria if properly designed and operated, low operator skill requirement.	Chlorine and ozone can create toxic byproducts, ozone and ultraviolet can be adversely affected by variations in organic content of greywater.
Aerobic biological treatment	Air is bubbled to transfer oxygen from the air into the greywater. Bacteria present consume the dissolved oxygen and digest the organic contaminants, reducing the concentration of contaminants.	High degree of operations flexibility to accommodate greywater of varying qualities and quantities, allows treated water to be stored indefinitely	High capital cost, high operating cost, complex operational requirements, does not remove all pathogens.

2.7 System description of greywater treatment technologies

Greywater treatment plant design is one of the difficult aspects of engineering and recycling greywater. There are different types of greywater treatment plants based on the quality and quantity of the liquid waste to be treated. In addition to the quality and quantity of the greywater to be treated, the selection of treatment process depends on the required land space for construction, the protection of the environment and the public health, avoid pollution of surface and ground water, and protect natural flora and fauna and the relative investment, personnel skilled required, familiarity of the technology in the city and running costs of the various treatment technologies for reusing of greywater. The most commonly greywater treatment technologies that are found from different literature are listed and organized by (Admasie, 2015) are described as follows;

- Conventional activated sludge system (CAS)
- Extended aeration activated sludge system (EAAS)
- Sequential batch reactor system (SBR)
- Trickling Filters (TF)
- Rotating biological contactor system (RBC)
- Stabilization ponds (SP)
- Moving bed biological reactor (MBBR)
- Membrane bio-reactors (MBR)
- Personalized greywater treatment systems (PGTS)

Table 5: different greywater treatment methods system description (Admasie, 2015)

No	System name	System description
1	Conventional activated sludge system (CAS)	The conventional activated sludge system is a biological treatment process that use bacteria suspended in liquid in order to remove organic matter, ammonia and nitrogen from the waste water.
2	Extended aeration activated sludge	The EAAS system is a similar biological treatment process to the CAS with a main difference in the sludge retention time (SRT) in the bioreactors. Moreover, the EAAS systems

	system (EAAS)	do not have primary sedimentation units.
3	Sequential batch reactor system (SBR)	The sequential batch reactor system is practically a CAS system, in which the operations of the bioreactors (carbonation, nitrification and de-nitrification/ phosphorous removal if required) and of the final settling tanks are performed in single tank.
4	Trickling Filters (TF)	Trickling filter is another system for biological treatment of wastewater. In these plants the bacteria are not suspended in liquid, as in activated sludge plants, but the microorganisms are attached on a medium fixed in the bioreactors. As the waste drips through the medium the organic matter is absorbed by the bacteria and utilized as food (carbonation). The slime layer of bacteria is about 0.1 to 0.2mm thick
5	Rotating biological contactor system (RBC)	The RBC is another attached growth treatment process principally composed of a complex of multiple plastic discs mounted on a horizontal shaft. The shaft is mounted at right angles to the waste water flow and approximately 40% of the total disc surface is submerged in order to achieve removal of the organic load and nitrification of the ammonia content. As the shaft rotates at a rate of between one and two revolutions per minute, the disc slowly revolves and bacteria grow on the disc plates by adsorbing organic materials from the waste water; these solids settle in the downstream settling tank. As the top 60% of the disc plate area passes through the air, oxygen is absorbed to keep the growths an aerobic state
6	Stabilization ponds (SP)	Waste stabilization ponds (WSPs) are large, manmade water bodies. The ponds are filled with waste water that is then treated by naturally occurring processes. The ponds can be used individually, or linked in a series for improved

		treatment. There are three types of ponds, (1) anaerobic, (2) facultative and (3) aerobic (maturation), each with different treatment and characteristics
7	Moving bed biological reactor (MBBR)	Moving media bio-reactors are systems that combine two existing technologies, namely the activated sludge systems (e.g. CAS, EAAS, SBR etc). The configuration of a MBBR system is similar to the CAS systems (anoxic/aeration tanks and final clarifiers), but in MBBR systems biomass grows on specific plastic media (bio carriers), instead of developing as flocs, which in turn eliminates the need for sludge recirculation. Moreover, due to the development of the biomass on the carriers in the tanks, the pollution loading rates can be much for the same level of treatment, than in a CAS system, thus allowing for much smaller volumes of anoxic/aeration tanks (smaller footprint of the treatment plant). A flow scheme of the MBBR configuration for carbon and nitrogen removal is given below.
8	Membrane bio-reactors (MBR)	Membrane Bio-reactors systems is an evaluation of the CAS system using state of the art technology for the separation of biomass from the treated effluent. The configuration of a MBR system is similar to the CAS systems (anaerobic/anoxic/aeration tanks), but in the MBR system the separation of the solids from the treated effluent is not achieved by gravity in the settling tanks but by filtration with the use of micro-porous membranes that retain the biomass and allow treated effluent to pass through
9	Personalized greywater treatment systems (PGTS)	Personalized greywater treatment systems are small scale systems which are made of a single or combination of physical, biological & chemical systems. They are designed without any high technology, most of them use pre filtration followed by aerobic and/or anaerobic treatments using

		different sized gravel and sand. They may contain chlorination as a disinfectant based on the reuse purpose of the greywater. These methods are being implemented widely in developing countries because they are affordable and they are also effective on treating greywater on site. Most of the common personalized treatment systems are: • H_2O Pure GWTS • The four barrel system • The two barrel system

2.8 Previous case studies on recycling GW for toilet flushing

The main intention of this review is to study different researches performed on the same title area as this study and implemented greywater recycling systems for the end purpose of toilet flushing. Unfortunately neither implemented greywater recycling system nor detailed study performed on the matter couldn't be found in Ethiopia, therefore reviewing other accessible studies and implemented systems was reviewed in this section in order to learn what to do and what not to do. The case studies were shortly reviewed on (A. A. Ilemobed, 2012), (Program, 2015).

2.8.1 Case studies with positive result

Palma Beach Hotel, Spain

(A. A. Ilemobed, 2012)

Palma Beach Hotel is a three-star hotel that has 81 rooms (63 of which include a kitchen) located on 9 floors. It is mostly occupied by foreign visitors (most of them from Scandinavia) who come to Spain for summer holidays. Usually, customers stay at the hotel for either 1 or 2 weeks. A simple greywater recycling system was introduced for toilet flushing with the aim of conserving the available potable water.

The treatment involved filtration using a nylon sock type filter (0.3 mm mesh size and 1 m^2 filtration surface), sedimentation, and disinfection with sodium hypochlorite. The treated greywater was initially stored in a ground level tank (4.5 m3) and from there was pumped using an automatic pump to a terrace tank, which could also be fed with drinking water, if necessary. From the terrace tank, the toilet cisterns in the rooms were fed by gravity.

The average toilet cistern is 6 liters and average consumption on site during the study was 36 l/person/day. While undertaking an economic analysis of the system, a 14 year payback period was computed. The payback period was based on the seasonal characteristics of the tourist industry with the system operating over an average of 7 months a year with average hotel occupancy of 85%. In terms of educating users and determining perceptions, an informative pamphlet was left in all the rooms. The pamphlet included a short introduction on the importance of water management, a description of the greywater reuse project, identification of the institutions involved, input for residents' personal data (nationality, age, gender, duration of stay at the hotel) and several questions requesting residents' perceptions regarding the reuse system (i.e. opinion on the 24 system and the quality of water in the toilet cistern).

Data from residents indicated a general satisfaction with the system. Unpleasant odors were mentioned by one of the hotel's customers who also gave a "fair" overall impression of his holiday period. No complaints about the system were reported to the hotel administration. The system has been proven to be sustainable in terms of energy consumption, land requirements and waste production. The system also showed durability (by operating for 1 year without any significant problems) and robustness (fluctuations in greywater composition did not affect the maintenance program). With adequate information given to users the social acceptance of the system was generally positive.

Institute Agronomique et Veterinaire, Rabat, Morocco

(A. A. Ilemobed, 2012)

This pilot study was conducted on the campus of the Institute Agronomique et Veterinaire (IAV), Rabat, Morocco which is located next to the Club of the Association Culturelle et Sportive de l' Agriculture (ACSA).

Wastewater generated in the showers and the toilets of the ACSA club gym is segregated thus allowing the collection of 8 m3/d of greywater. A reservoir outside the gym collects greywater which was then pumped through a 50-mm diameter pipe over a distance of 504 m to the wastewater treatment facility located inside the IAV Campus. Greywater is then treated in a two-step gravel/sand filtration unit.

Step 1 consists of a planted horizontal-flow gravel filter, while step 2 is a vertical-flow multilayer sand filter. The horizontal-flow gravel filter is constructed of reinforced concrete and has the following characteristics: length = 2.25 m, width = 2.0 m, and cross sectional area = 1.6 m2. After passing through the filters, greywater is disinfected in an Ultra-Violet Tspa. The treated and UV disinfected greywater is then stored in a black, polyethylene reservoir and conveyed, using a 50-mm diameter pipe, over a distance of 460 metres to the building housing the Department of Rural Engineering (DRE). The four toilets on the ground floor of this building are connected to the greywater supply pipe.

A dual piping system was adopted in the DRE building toilets to avoid any cross connections between potable and recycled greywater. Hence, the toilet cisterns have access to potable water when greywater is not available figure below. For comparison purposes, 4 other toilets, located on the first floor of the DRE building, were flushed with potable water. Dual piping supplies (grey and potable water) into toilet cistern The performance of the two-step unit was satisfactory.

The effluents' average turbidity was reduced from about 28 to 2 NTU. Removal rates of COD and BOD5 were 75% and 80% respectively. Half of the nitrogen was nitrified during the filtration process, the removal rate of phosphorus was almost 50%, while anionic surfactants were removed at a rate of 97%. On the other hand, the gravel/sand filter performance in Faecal Coliform removal was low and did not exceed one log unit.

Figure 2: Toilet flush with two source of water

2.8.1 Controversial/failed case studies

Quayside Village Vancouver, British Columbia, Canada

(A. A. Ilemobed, 2012)

Quayside village (QV) is a co-housing community located in the City of North Vancouver British Columbia. As a multi-agency supported demonstration project, Quayside's greywater system had to be reviewed and discussed with a number of agencies. Government municipal staff expressed concern about possible liability for water-related sickness. For this reason, a conservative greywater reuse system with several backup features was permitted, with treated greywater to be used for toilet flushing. The reuse system included the following components

- ✓ A septic tank to remove coarse solids and grease/oil;
- ✓ A bio-filter with recirculation back to the septic tank inlet;
- ✓ A slow sand filter to remove solids;
- ✓ Ozone generator and contact tank which was subsequently replaced by chlorination;
- ✓ A slow sand filter for automated back-washing, and
- ✓ A storage tank. Figure below. Quayside Village greywater reuse System

Although the system operated for over three years, there were a number of equipment failures that interfered with the system being able to meet the regulatory requirement of six continuous months of operation. One of the key problems initially identified was the reliance on ozone as the sole means of disinfection, compounded by the lack of adequate ventilation for the ozone gas residue. The following remedial measures were then implemented:

- The ozone generator contact tank was removed and replaced with a chlorination system. This eliminated the problem with the ozone gas residue and provided a chlorine residual to control there-growth of bacteria
- The cloth fabric which was intended to assist in removing colloidal particles was removed from the septic tank. This was because the structure supporting the fabric in the tank collapsed and blocked the outlet.

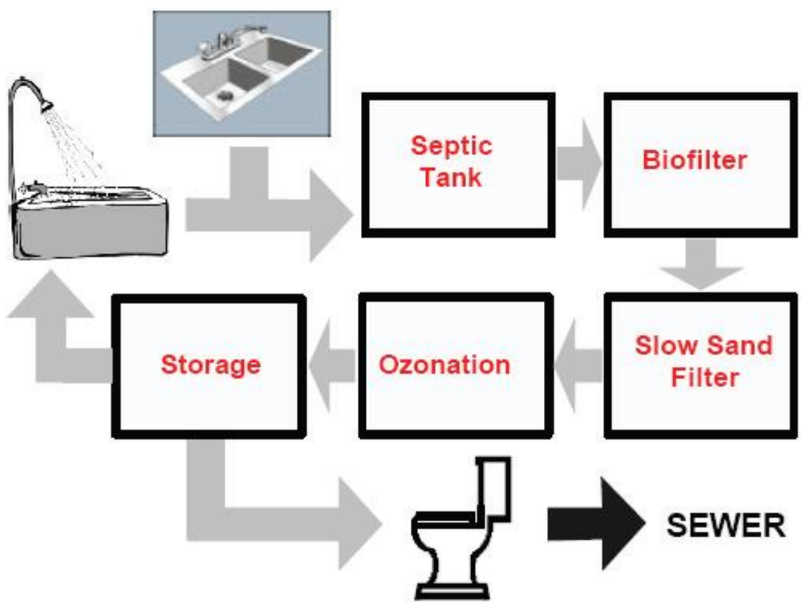


Figure 3: Greywater Treatment design of Quayside Village

Lessons Learnt

System design and function should be resolved with the relevant authorities before reuse equipment are purchased and the system installed. This is because municipalities would generally require a conservative system that will be robust enough to prevent risks to public health and safety.

Linacre College, Oxford, United Kingdom

(A. A. Ilemobed, 2012)

Linacre College houses the first domestic water recycling scheme in the UK. A student residence housing 23 occupants was built in 1995 using “environmental friendly” or recycled materials in order to cut down on energy and water demand. One of the conservation aspects was the reuse of greywater for toilet flushing.

A survey conducted prior to the project showed that 40% of the occupants were concerned about the potential odour and smell of the treated water but would consent to the plan if these were eliminated. The first scheme comprised a bag filter and a depth filter. Due to severe problems, however, the plant operated for only two days. Subsequently, Anglian water services Ltd, Huntingdon, undertook a series of process selection trails (Murrer and Wards, 1997) to identify a suitable system for the scheme, and a number of sand filters and membranes were tested. A trail house with a selected process was identified and used in investigating the cause of the earlier problems. This led to the second stage of the Linacre scheme where the greywater was treated using a depth filter and a membrane. Greywater from baths, showers and hand basins was collected in a tank and filtered through a 4 inch diameter sand filter (Murrer and Ward, 1997).

This was followed by further filtration using a hollow fiber ultra-filtration membrane with pore size of 0.01m. The filtered effluent was collected into a tank located in the loft of the house. The effluent in the tank may be topped up with potable water supply from the mains when necessary in order to supply enough water for toilet flushing. The effluent was then disinfected with chlorine prior to use. Some of the effluent from the ultra-filtration membrane was used to backwash the sand filter. A 5 log reduction in bacteria was attained through this treatment train and viruses were not detected in the effluent.

After a few months of operation, the system suffered some operational difficulties. Operation and maintenance costs were found to be high due to excessive membrane fouling resulting in low flux (Ward, 2000). Raw greywater was partially digested under anaerobic conditions in the lengthy collection network resulting in poor permeate quality and odour problems from the network. Consequently, a further process modification was done and this time a biological system (Ward, 2000) was incorporated. The process scheme now comprises a bioreactor followed by a sand filter, an activated carbon column and chemical disinfection. Further development of the membrane cleaning procedure was undertaken to reduce membrane fouling from fats and other organic material in the greywater treatment system. The system has been effectively working since then.

Lessons Learnt

1. Perception surveys of the consumers and the local authority was very important before the implementation of the reuse system.
2. Public enlightenment campaigns incorporating the concerns raised, helped to educate consumers on the benefits of the reuse system. Positive community attitudes towards recycled water use have been identified as a key component of the success of a water reuse project (Po et al., 2003).
3. Prior to the choosing of water reuse treatment equipment, project managers should talk extensively to manufactures about the technical issues and processes involved. This is to ensure that the components are compatible and can synergistically work as a system. The challenges of using smaller membrane sizes resulting in membrane fouling, poor permeate quality, and odour problems may have been avoided in the above scheme.
4. Realistic timelines should also be negotiated and understood by the engineers, architects, project managers, residents and municipal staff.

2.8.3 Important issues from the case studies

.

- ✓ Long pay-back periods tend to infer non-profitability, and thus tend to dampen public and decision-makers' interests in greywater reuse. The case studies reviewed indicate that on average, greywater systems had a payback period of between 8-14 years (Sayers, 1998) (A. A. Ilemobed, 2012)with preference for between 2-4 years amongst potential respondents in Melbourne, Australia (Christova-Boal, 1996) Large housing developments have provided more tangible economic benefits than smaller ones as a result of economies-of-scale
- ✓ The most economical applications for many greywater systems were in combination with rainwater.
- ✓ The recycling of greywater needs to be done in such a way as to avoid the building up of impurities. The use of a final, polishing filter in the treatment plant would then seem to be an essential component of the treatment plant.
- ✓ The technologies used to treat greywater for reuse must be effective in dealing with organic material, solids and pathogens. The different greywater recycling schemes reported to date, have however achieved very different performances. Simple technologies and sand filters have been shown to have only a limited effect on greywater, whereas membranes have been reported to provide good solids removal but cannot efficiently tackle the organic component. Microorganism removal was achieved in schemes that included a disinfection stage or membrane bioreactor.
- ✓ Disinfection of greywater for utilization in flushing toilets and urinals was stressed in order to eliminate pathogenic organisms which have potential to impact negatively on public health if ingested.

CHAPTER 3

3. Methodology

3.1 Selection of the study area

Addis Ababa, capital city of Ethiopia, established in 1886, which is located in the middle of the country, it is situated at 9°01′29″ N latitude, 38°44′48″ E longitude, and at an altitude ranging from 2,100 meters above sea level at Akaki in the south to 3,000 meters above sea level at Entoto hill in the north with the total area estimated around 540 km² (PPSA, 2013) The population of the city is around 4.1 million with an annual growth rate of 2.67% (Ethiopian statistics agency). The average annual temperature is 23 Cº and the average annual rainfall is 1089 mm (Agency, 2018) the city is the social, political and economic center of the country for more than 100 years. The city administration system includes the city government at the top level, 10 sub-city in the middle level and 116 woredas at the bottom level. (Central Statistical Agency, 2010)

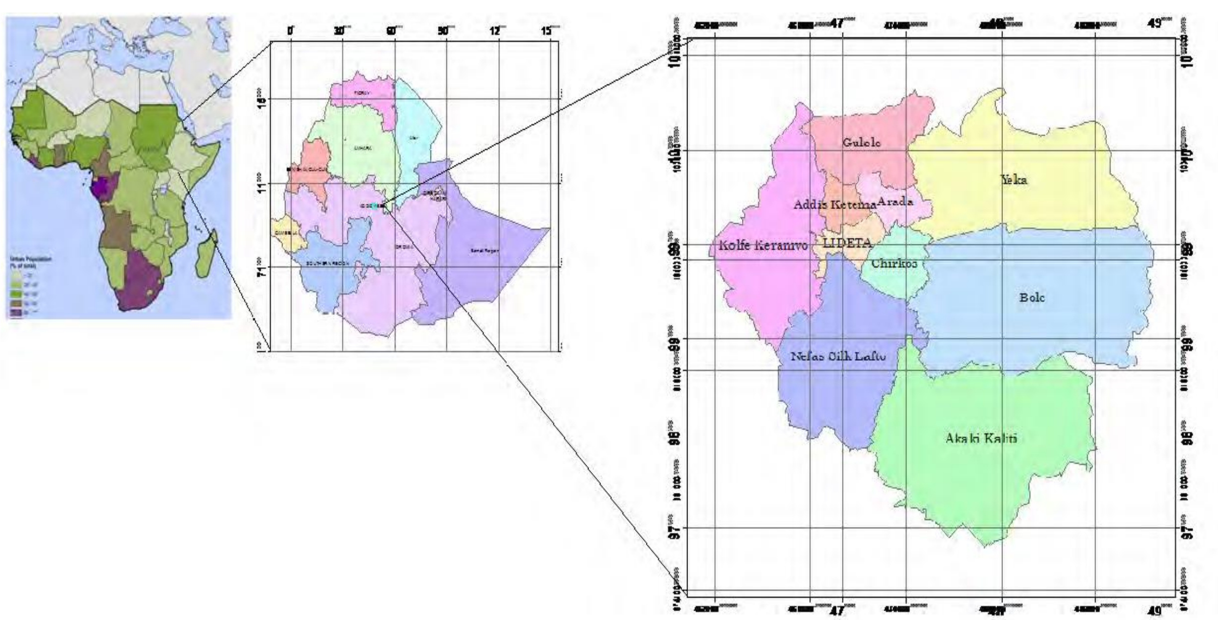


Figure 4: Location Map of Africa, Ethiopia & Addis Ababa

The case study area selection criteria were based on consideration that it answer the research questions, therefore, on the selected case study area:

A. There is a huge water shortage problem in the block.
B. The study area is familiar to the researcher so that the study will be cost effective and accurate data's can be collected on social and technical matters due to the trust built in the community.

Based on those points Summit condominium was selected. Summit condo is located in Bole sub city Addis Ababa, The land area covered by Bole sub-city is 11,849.49 hectares. This constitutes 22.8% of the total land area of the city which makes it 2nd next to Akaki in land area coverage from the ten sub- cities. Among these fourteen woredas, the largest area is covered by woreda 10 with 2752.31 hectares that is 23.23% of the total land area, and woreda 02 covers the smallest land area of 117.22 hectares which is 0.99% of the sub city land area (AAHCPO, 2015). Among that fourteen woredas, woreda 10 is where Summit Condominium located, which is located at eastern part of Bole sub-city, a new settlement area. Populations that live in Summit Condominium Houses are estimated more than 30,000 people within 11,430 households (informed from woreda 10)

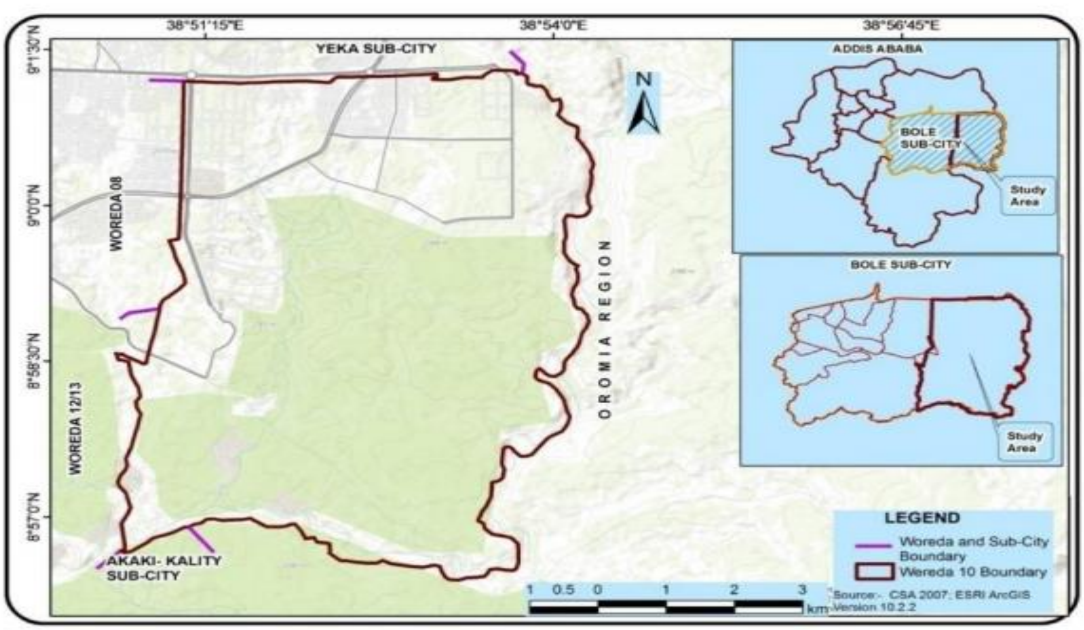


Figure 5: Map of Woreda 10, Bole Sub city, Addis Ababa

From all those blocks in the condominium B-349 was selected. The block exists around in a place locally known us “*cherkos”* which is a familiar location to the researcher, the block is inside a gated condominium of 4 blocks as shown in the figure below, all four of the blocks suffer hard from the lack of water on the daily basis and block-349 was taken as a sample block for this study.

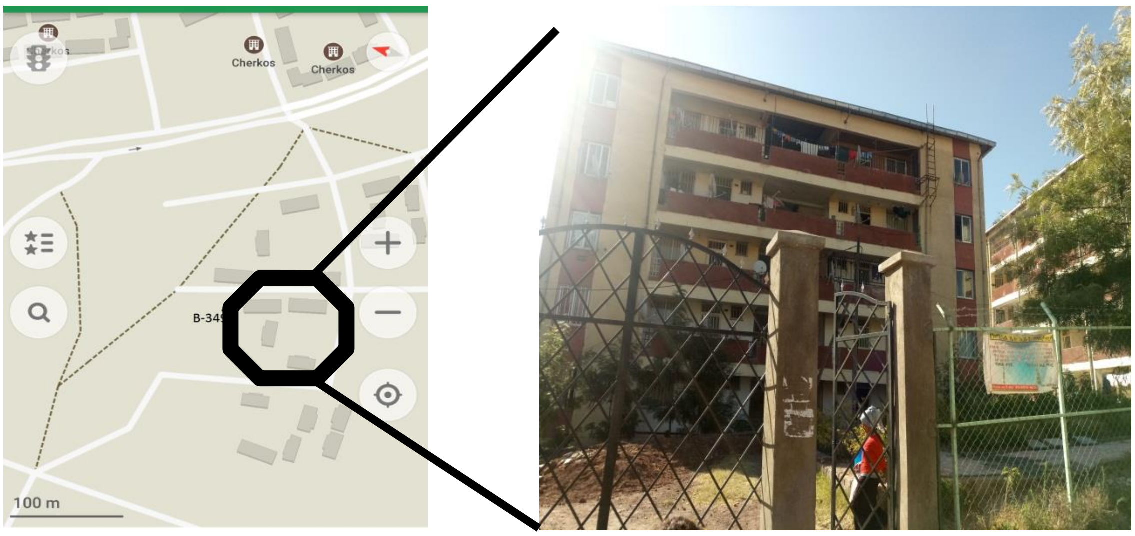


Figure 6: Location Map of the gated compound and picture of Block-349

Block -349 is the block shown in the left picture at the center part of the circled location and it can be seen as the condominium on the right picture. The compound have the total household of 100 households with the total population around 352 peoples, out of the four blocks two of them have 30 households each and the other two have 20 households each. And Block 349 have 20 households and accommodated around 70 peoples.

3.2 Research methods

Qualitative and quantitative methods of data collection were employed in this research. The qualitative method was used to gain a better understanding of the site water shortage, resident’s opinion on the proposed greywater reuse method, experts opinion on the design guideline of greywater reuse and to characterize the quality of the greywater generated form the households through interviews, questionnaires and standard lab tests.

The quantitative data collection method was used in the household survey to explore information about their daily water consumption, daily greywater generation and amount of money they spent per month on water. In addition to that quantitative data's were collected from *Addis Ababa Water and Sewerage Authority* and *City government of Addis Ababa saving house development Enterprise* about current water supply status, water demand status, population number living under the condominium and sanitary design of the condominiums.

In addition, the Multi-Criteria Analysis (MCA) method was used to choose from alternative greywater treatment methods. The researcher prefers MCA due to the reason there is no guideline for the construction of greywater treatment method in Ethiopia and MCA is often applicable on such cases for gathering data directly from the stakeholder and the MCA is the appropriate method for the all-embracing comparison of the alternative treatment options.. Open-ended approach was adapted to allow the respondents to answer based on their willingness without forcing them by restrictions. Based on this scoring and weighing of different methods was conducted and the result led to a lab-scale construction of the method, with the proper loading rate an retention time.

3.3 Sampling and household selection methods

3.3.1 Sampling

Sampling was needed because of two main reasons; one is sample households for the questionnaire and sample households to take greywater samples for laboratory tests.
The total number of sample household determined from the total households. Since the study area is small, the total number of the households was sampled by 90% confidence level and 10% error for the greywater sample and by 90% confidence level and 10% error for the questionnaire.

In order to determine the appropriate and valid sample for the study, scientific sampling formula explained by (Yamane 1967:886; see also Boniface, 2014) is used.

$$\boldsymbol{sample\ household/peoples(\mu)} = \frac{\boldsymbol{N}}{(\mathbf{1} + \boldsymbol{e}^{\mathbf{2}}\boldsymbol{N})}$$

.

N- Total number of households/people in the sub city, e - error (%) and μ - sample population. Based on the calculation, out of 20 households in the study area, 16 sample households were selected for the greywater sample and 41 peoples were surveyed for the questionnaire.

3.3.2 Households selection method

Due to the nature of the research, non-probability sampling method was used in order to select households for the questionnaire. This method is effective to reach a particular targeted population (Thompson, 1997), but almost all households were covered during the survey. The influential person (bock-coordinator) took a vital role to inform the residents about the proposed project in order to build trust between the researcher and the residents in addition to that households were selected based on personal observation by talking to the residents in the block based on two criteria’s

1. The person’s capability to answer the questions properly
2. The person’s willingness to participate in the questionaries’

3.4 Data sources

As Yin (2014) mentioned, data and information are a source of evidence for the case study research. For this research, various types of primary and secondary data collected from different sources. Secondary sources obtained from peer reviewed articles, different websites, published reports and books, Addis Ababa Water Sewerage Authority (AAWSA), Environmental Protection Agency (EPA), Addis Ababa housing construction project office, Bole Sub city administration and the Central Statistics Agency.

1. **Questionnaires**: The survey was undertaken by using semi structured and structured questionnaire. Structured questions are useful to gather information, which doesn't any elaboration (Gill et al., 2008). The households provided their answers according to their own reality. The questionnaire of the households, addressed; their income level, how they manage water scarcity, the cost of water, water consumption behavior, waste water generation and so forth (Appendix). On the other side, the questionnaire helped to cross check the information gathered from water organizations interview regarding the water supply status of the condominium. Details of the methods in the questionnaire used in order to produce a well-designed questionnaire and to assist in getting the correct information are listed below.
   a) **Test run survey:** 5 houses was randomly selected and tested for the questionnaire in order to check the questionnaire was clear enough for them to understand then some minor details were changed and the whole survey was conducted.
   b) **Length of the questionnaire:** The length of the questionnaire was designed in two page in length. The reasons for this are that surveyed users should not be intimidated by the view of a long questionnaire. People are busy and not always willing to appoint more than 10 /ten/ minutes for answering a questioner. The response then would be low and it would be possible that a low amount of questionnaires would be answered and results would not be valid.
   c) **Layout:** The layout and presentation of the questionnaire was designed in a way that it is easy to answer and friendly to the user. Issues like size of font size and the answering way was considered.
   d) **Language:** The language used to express the questions needed to be simple and concise. Questions translated from English language to Amharic language people could answer the questionnaire easily and would not misunderstand any of the questions. No matter how much effort is put in designing a questionnaire there is always the possibility that some questions are not clear or that it is not easy to be answered.

2. **Interviews:** This helped significantly to gather information on the current status of water supply situation in the summit condominium specifically in Block-339 including what will be the perception of the residents on greywater recycling and design considerations on greywater recycling system. Face to face, interview was conducted with the Addis Ababa Water and Sewerage Authority experts, EPA (Ethiopia) experts, Addis Ababa housing construction project office experts and some selected residents who are educated and influential in the block. The researcher used unstructured and semi-structured interview questions (see Appendix A). These methods are helpful to elaborate important information to the participants and to receive required enough information. Unstructured interview is helpful to get a detailed information beside it is useful to gather a new knowledge even though it is time taking. Semi structured interview chosen because it gives a direction to the participant what to talk about, so it is not time consuming, easy to manage, it avoid unhelpful data and reduce confusing (Gill, 2008) Therefore, if the data required detailed information applied unstructured interviews, if not, semi-structured interviews was applied for the respondents.

3. **Lab tests:** 16 Samples were collected from 16 households of the study selected block residents. Greywater about 1-3 litter from each household was taken in order to approve the quality of greywater collected was a fair representative and they were automatically transported to the lab. Then laboratory water tests were performed to know and to compare the influent and effluent greywater quality of the parameters BOD5, TS, TSS, TDS, TVS, COD, DO in mg/l PH and microbial content values taking influent samples from the mixing 16 household samples and one sample from effluent. All the lab tests were conducted by APHA standards. The value of PH and DO is directly measured whereas the following formulas can be applied to calculate the values of TS, TSS, TDS, TVS,COD and Microbial content.

a) Total solids (TS)

$$\boldsymbol{Total\ solids}\frac{\boldsymbol{mg}}{\boldsymbol{L}} = \frac{(\mathrm{A} - \mathrm{B})\ \mathrm{X}\ 1000\ (\mathrm{TAHD}, 1999), \mathrm{TAHD}}{\mathrm{mL\ sample}}$$

Where:

A = weight of dish + residue, mg

B = weight of dish, mg

Total suspended solid (TSS)

TAHD = Technical Assistance Hydrology Project

$$\boldsymbol{Total\ solids}\frac{\boldsymbol{mg}}{\boldsymbol{L}} = \frac{(\mathrm{A} - \mathrm{B})\ \mathrm{X}\ 1000\ (\mathrm{TAHD}, 1999), \mathrm{TAHD}}{\mathrm{mL\ sample}}$$

Where:

A = weight of dish + residue, mg

B = weight of dish, mg

Total dissolved solids (TDS)

TDS=TS-TSS (TAHD, 1999

b) Total volatile solid (TVS)

$$\mathrm{Total\ Volatile\ Suspended\ Solids\ mg/L} = \frac{(\mathrm{B} - \mathrm{C})\ \mathrm{X}\ 1000\ \mathrm{mg/g}\ (\mathrm{Schumacher}, 1989)}{\mathrm{Sample\ volume}}$$

Where;

B = Weight of residues + dish, mg

C = weight ignition, mg.

c) Biological oxygen demand (BOD_5)

$$\mathrm{BOD_5, mg/L} = \frac{(\mathrm{DOi} - \mathrm{DOf})\ (\mathrm{Delzer}, 2003)}{\mathrm{P}}$$

Where;

DOi = DO of diluted sample immediately after preparation, mg/L

DOf = DO of diluted sample immediately after 5 days incubation at 20oc, mg/L

P = decimal volumetric fraction of sample used

$$P = \frac{\text{Volume of sample}}{\text{Volume of bottle}}$$

d) Chemical oxygen demand (COD)

$$\text{COD as mg } O_2/L = \frac{(A - B) \text{ X M X } 8000 \quad (\text{IITD}, 2013)}{\text{mL sample}}$$

Where:

A = mL FAS used for blank

B = mL FAS used for sample

M = molarities of FAS, FAS= Standard ferrous ammonium sulfate titrant

8000 = milli-equivalent weight of oxygen X 1000 mL/L.

$$\text{Molarity (M) of FAS solution} = \frac{\text{Volume 1.5 ml } K_2Cr_2O_7 \text{ solution titrated, mL}}{\text{Volume FAS used in titration, mL}}$$

e) Microbial content

Serial dilution method was used to calculate the microbial and it was calculated by

$$\text{CFU} = \frac{\text{Number of Triplicate} * 1/\text{inverseofserialdilution}}{\text{Amount of transfer, mL}}$$

All these tests and treatment methods are being performed to meet the standard of the treated greywater for toilet reuse.

Table 5: The Greywater Standards for reuse of the effluents for indoor and outdoor use

No	Parameters	Unit	Emission limit	Use
1	Biological oxygen demand(BOD_5)	mg/l	76-200	For
2	pH	mg/l	5-8.1	Toilet flushing
3	Total solid(TS)	mg/l	<3150	Fire fighting
4	Total Suspended solid(TSS)	mg/l	70-150	Gardening
5	Total volatile solids(TDS)	mg/l	<3000	Car washing
6	Total dissolved solids(TVS)	mg/l	212.5-487.5	Irrigation
7	Dissolved oxygen(DO)	mg/l	2-4	(Febri, 2005)
8	Chemical Oxygen demand(COD)	mg/l	56-890	
9	Microbial content	CFU	$29\text{-}307*10^3$	

3.5. Analysis of data

The data collected through different ways were analyzed in to two forms; the raw data collected from the households response was analyzed by using Excel spreadsheets. The result from Excel was interpreted and presented by using tables, charts, graphs and descriptive analysis. The qualitative data gathered through the interview and the lab tests was recorded and analyzed by a scientific ways based on the theories and technical guidelines from literature review.

Combining the two analyzed inputs another two major research analysis's were made

1. **Greywater treatment technology selection**

Selection of decentralized greywater treatment technology was selected and systematic design of greywater recycling method was incorporated on the lab scale. The methods chosen in this thesis for greywater treatment considers different types of decentralized greywater treatment technologies that consists of a variety of approaches based on the quality and quantity of the liquid waste to be treated, the required land space required for construction, the protection of the environment and the public health (avoid pollution of surface and ground water, and protect natural flora and fauna), the relative investment and running cost, personnel skilled required and familiarity of the technologies for reusing of greywater for mass condominium houses. This comparative approaches were evaluated and compared based on literature review of selected decentralized greywater treatment technology and from the interview results that was addressed from professional engineers from AAWSA, EPA (Ethiopia) and AAWSA.

2. **Lab scale greywater treatment method design**

The basic concept of constructing a lab scale greywater treatment method was to show that the concept of greywater recycling for the reuse of toilet flushing can be done for Ethiopian mass housings in order to help the huge water scarcity happening in the city and the lab scale can show a little light for future studies so that a pilot scale and a full scale greywater recycling systems can be implemented in real time.

The lab scale construction was based on the technology method selected using the method of Multi-Criteria Analysis and in addition to that the lab scales treatment method was selected based on two factors:

1. The finance available to construct a lab scale technology
2. The time and technology available to construct the lab scale technology

3.6. Limitation of the study

Hence, the research scope focused on greywater recycling method for the purpose of toilet flushing in a single block, the results found may not represent all the blocks in the study area or other condominium sites accurately, Lack of frameworks and standards regarding greywater recycling in Ethiopia was also another hindering fact, Lack of enough information from secondary sources due to unwritten and unorganized documents were also another big constraints as well. In addition to that time and finance constraints were also the other factors that challenge the researcher from looking at the issue in very detailed manner than he already did.

3.7. Summary of research design

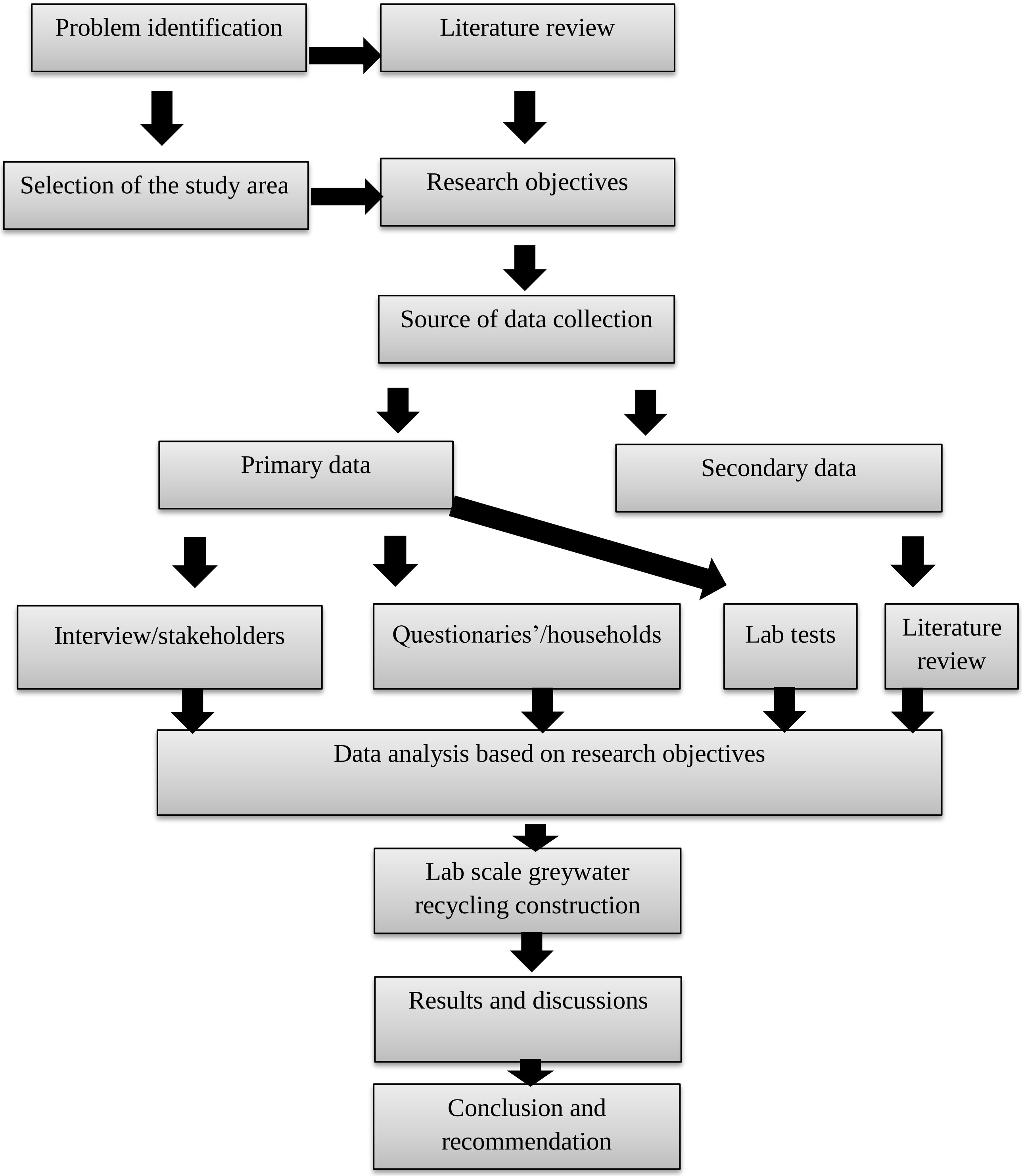


Figure 7: Summery of the research design

CHAPTER 4

4. Pre-design Data Analysis

4.1 Social issues concerning greywater recycling

Considering the social aspect of any new project or research is the first step because the people living in the area are the one's giving the acceptance or rejection of a new system. Therefore, positive public opinion is the key to success for the proposed reuse system. With that in mind a careful questionnaire was developed with closed –ended questions in Amharic language (as most of them find Amharic more easier than English) to observe the public opinion, since this design focus on block-349 all the residents in the block were given the questionaries' after a brief description of the intended study.

In addition to the questionnaire interviews with open ended questions were held with residents who have a better understanding of the study and experts from AAWSA,EPA and AAHCPO, since the interview focused on experts technical terms and English language was used.

The questionnaire consisted of Personnel information in summit condominium block 349 residents, their opinion about water services provided by AAWSA opinion about greywater reusing. Interview was held mainly for the purpose of selecting a treatment method to prioritize the design parameters.

4.1.2 Questionnaire result from block-349 residents

PART I- Personal information

Question 1: what is your sex?

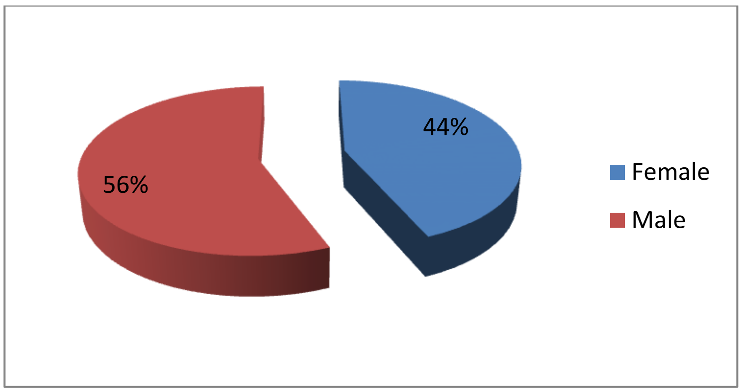


Figure 8: Category of sex

Regarding the category of sex from the study sample as indicated in the above figure shows that 56% of the samples are males and 46% of the samples are females.

Question 2: what is your Age?

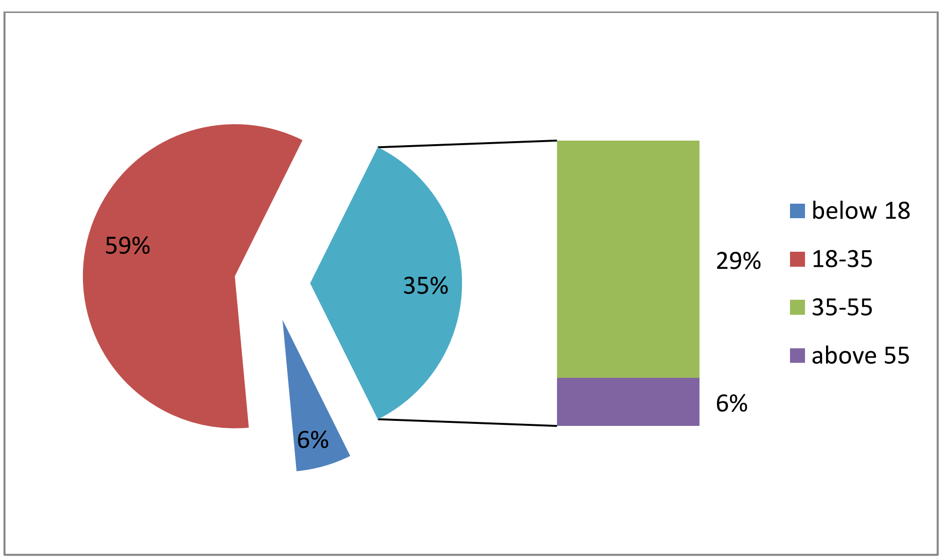


Figure 9: Category of Age

As we could have probably imagine condominiums are full of young adults and as the study shows 59% are between the age of 18-35 this particularly is a good news because most people in this age group are open to new ideas that means pitching the idea of greywater recycling in condominiums can receive a wide acceptance, 29% are between age 35-55 and the age group under 18 and above 55 were both at 6% in the survey.

Question 3: what is your Education level?

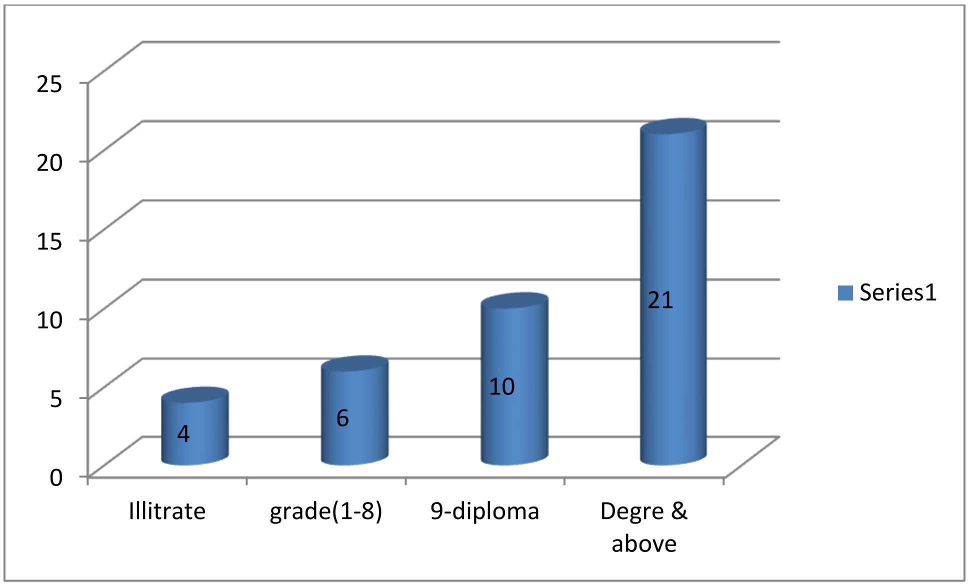


Figure 10: Education Level

According to the questionnaire almost 60% of the samples were people who have an education level of degree or above, this tells us that if we can teach the people the exact use and reason of greywater recycling, the concept might be accepted through education. Besides the above number the additional 23% of the sample have an education level of "Grade 9- Diploma" this will also add a value to the above point. The remaining education levels which are "Grade 1-8" and "Illiterate" have 12% and 5%.

Question 4: what is your income level?

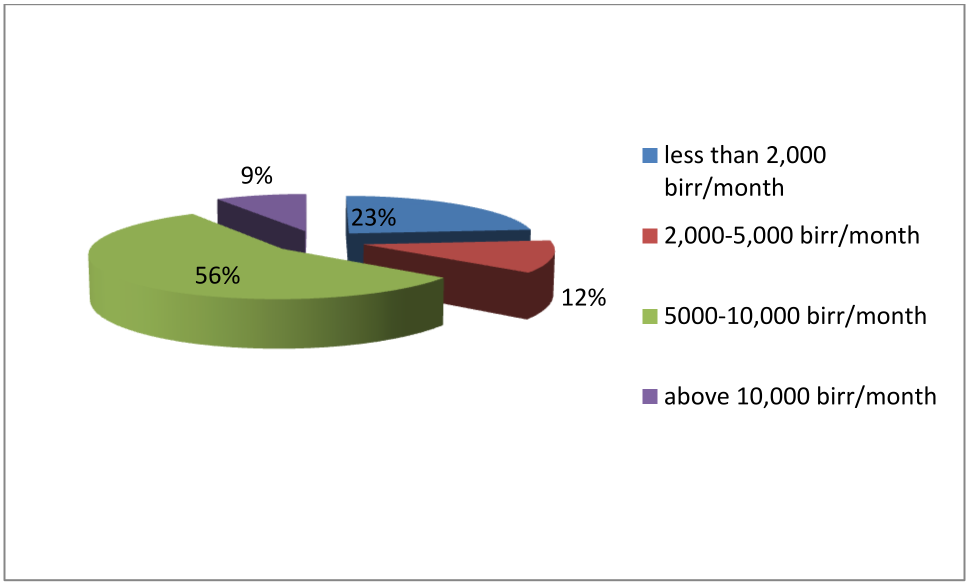


Figure 11: Category of income

The income distribution of the study sample by monthly income as indicated in the above figure shows that 56% of the sample earns between 5,000-10,000 ETB per month, 12% of the sample earns between 2,000-5,000 ETB per month, 9% of the sample is above 10,000 ETB and 23% earns less than 2,000 ETB per month. As interpreting this data from a financial stand point, most peoples don't even earn enough money to meet ends meet therefore any design plan which will cost the residents more money than what they are already spending may not be a positive idea.

Question 5: what type of mechanism do you use to wash cloths?

Since laundry water is a big source of greywater we need to study what type of mechanism they use to wash cloths, whether they use machines or their hands, we need to study this because we need to know where they spill the used water if a significant number of people use hands to wash, and according to the survey on the samples the following data was measured.

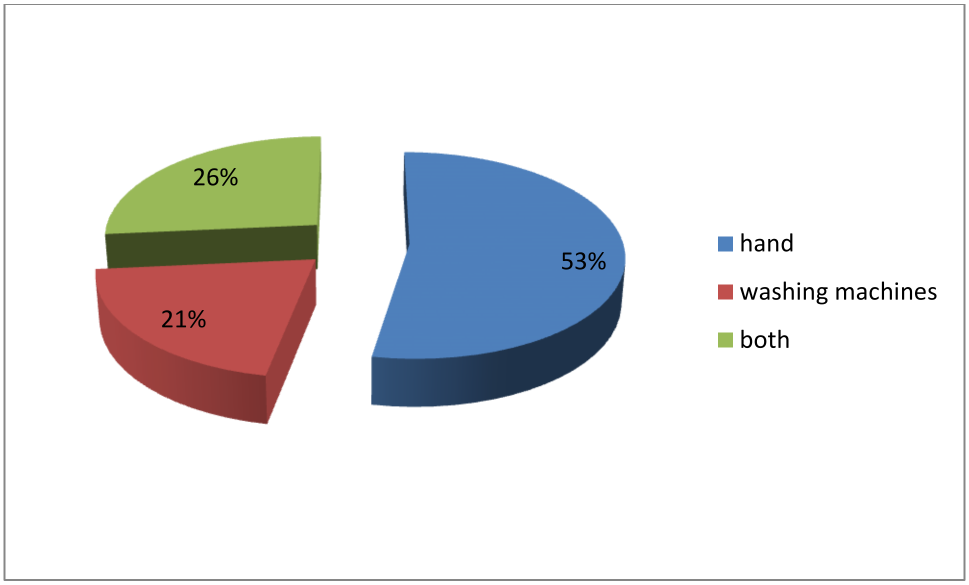


Figure 12: Mechanism residents use to wash cloth

As we can read from the above data almost 59% of the sample households use hands to wash water, this is due to two major reasons, the first one is washing machines are a bit expensive for the community and the second one is people don't see the use of buying washing machines because there is no tap water most of the time. The other 21% wash using machines by waiting for the tap water, the remaining 26% have washing machines but they also use hands to wash cloth due to the scarcity of tap water. the survey also conducted where the sample residents spill the waste water being generated from washing clothes.

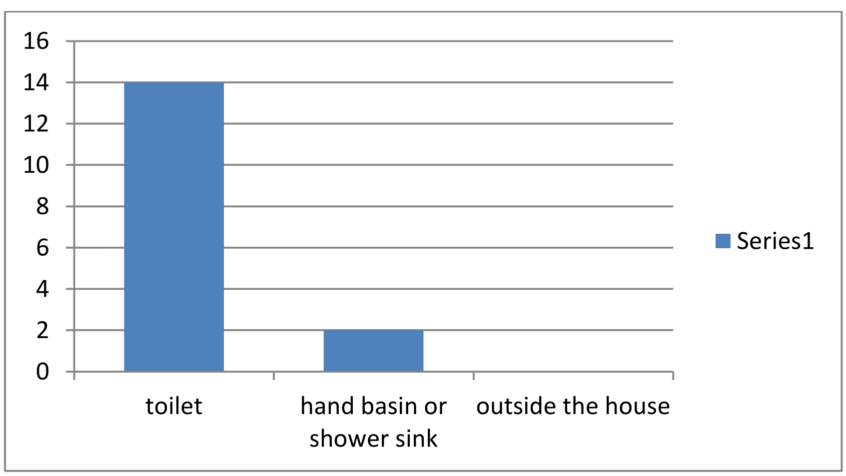


Figure 13: Where do the residents spill wastewater from cloth washing

The survey showed 87% of the sample who used both hands and machines to wash cloths, spill the water in the toilet, this shows even if the greywater system is installed and people continue spilling the waste water it in the toilet, this might cause a shortage in greywater production, therefore education on where to spill the water and design techniques needs to be applied to mitigate this problem.

PART II- PERCEPTION/OPINION

Question 1: how do you express the water supply in your condo?

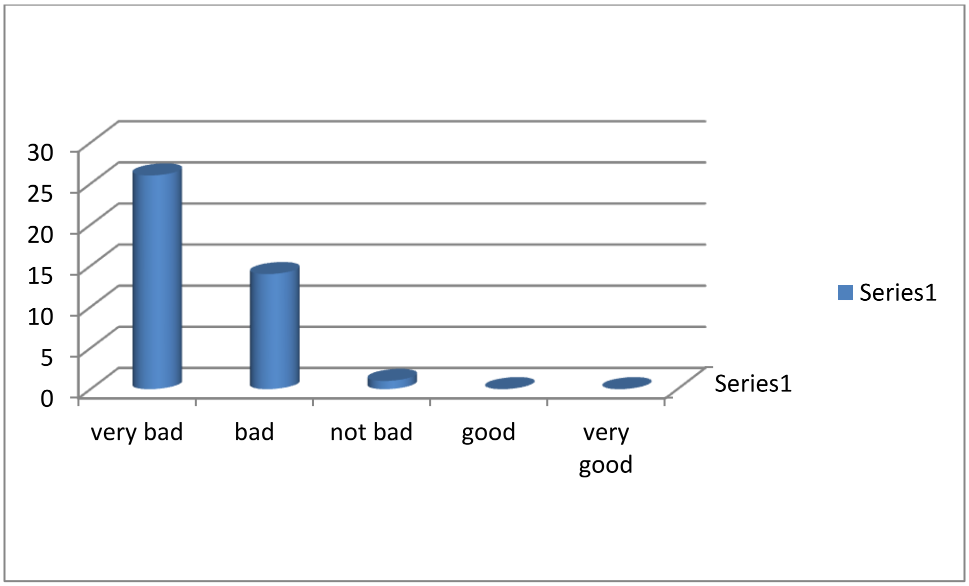


Figure 14: Opinion of residents on water shortage

As we can read from the above graph, almost 97% of the sample thinks they are living in a condominium where the water supply is “Bad” or “Very bad” while the remaining 3% thinks it’s not bad comparing to other worse condominiums but no sample said the water supply is “very good” or “good”, this data can justify the problem statement of the study and the need to think of alternative methods to satisfy the basic need of the residents.

Question 2: have you ever heard or know about greywater recycling system until now?

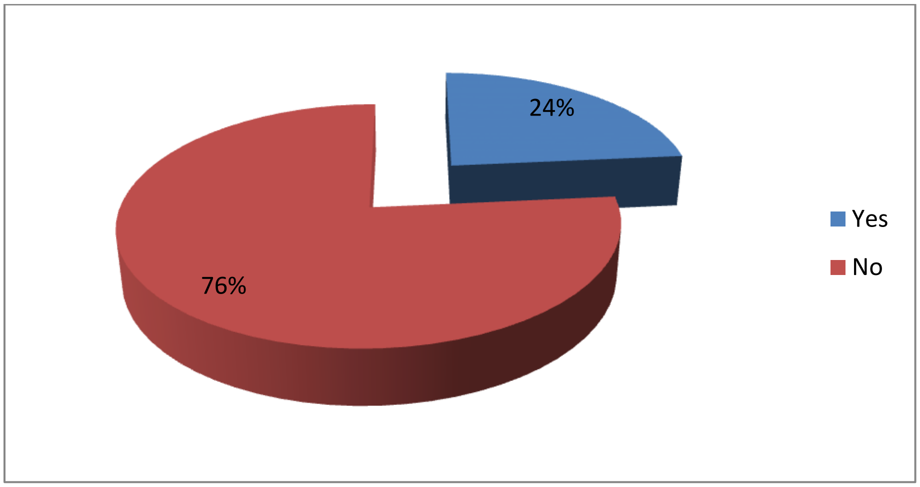


Figure 15: Residents knowledge about greywater recycling

The above pie chart indicated that 76% of the sample never heard about greywater recycling while the remaining 24% somehow know a little about greywater, from this data we can tell that educating the residents should be given a great deal of emphasis when trying to implement such systems.

Question 3: would you be comfortable if greywater from your house get recycled back to your toilet?

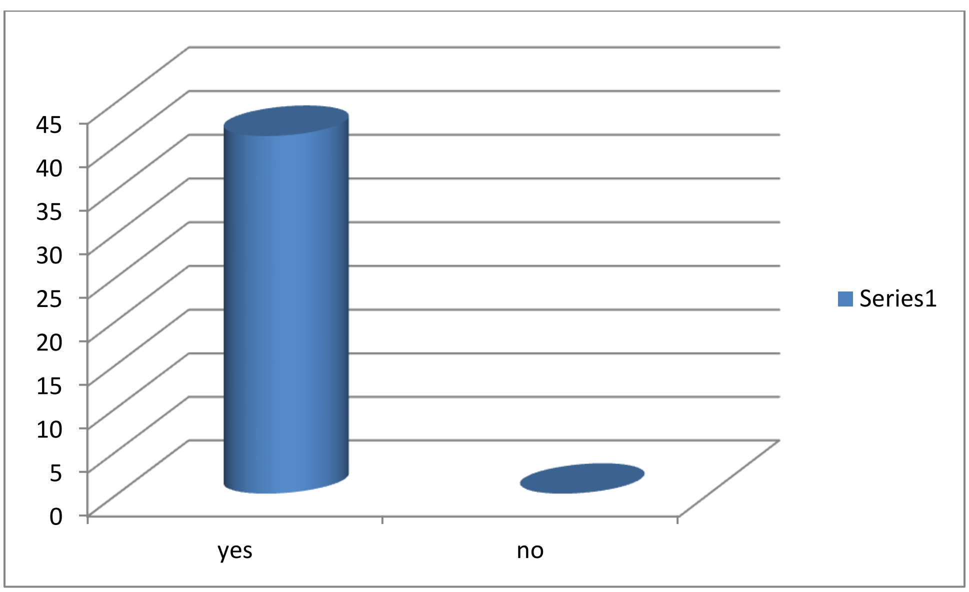


Figure 2: Willingness of the residents to use greywater

Amazingly 100% of the sample residents said they will be fine if the greywater get recycled back to their toilet, this result may be a result of the residents frustration by the lack of water in their building or their little knowledge about the process, but one thing is certain if the recycled water meets the standards, people are willing to accept it.

Question 4: will you be fine if the existing plumbing installation change? Which will include the reconstruction inside your house?

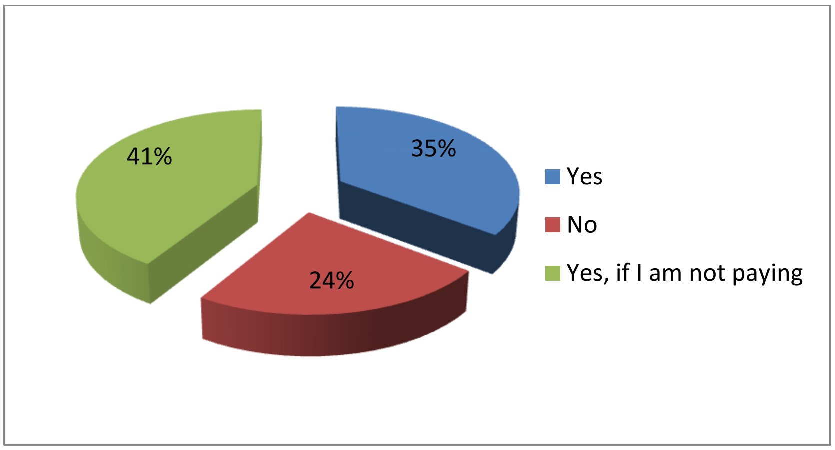


Figure 16: Willingness of residents for installation of greywater

This question was asked to check how much willing are the people for the proposed recycling system. And the result showed 41% of the samples were willing for the new system which will include a reconstruction of their kitchen and bathroom if they are not paying for the construction. The other 35% were willing to accept the change even if it means paying for their plumbing reconstruction. The remaining 24% thinks they are not willing to any reconstruction inside their house even if they are not paying for the reconstruction. This result tells that, it is better to integrate the recycling system from the initial construction of the houses so that 100% of the resident will be using the system, or intense education is needed to change the mind of the 24% residents who are unwilling to any change in addition to financing the project without the residents money (meaning with long pay pack period) and maybe using laws to enforce this projects.

Question 5: how do you express the price of water you get on the tap and the water buy when there is no tap water?

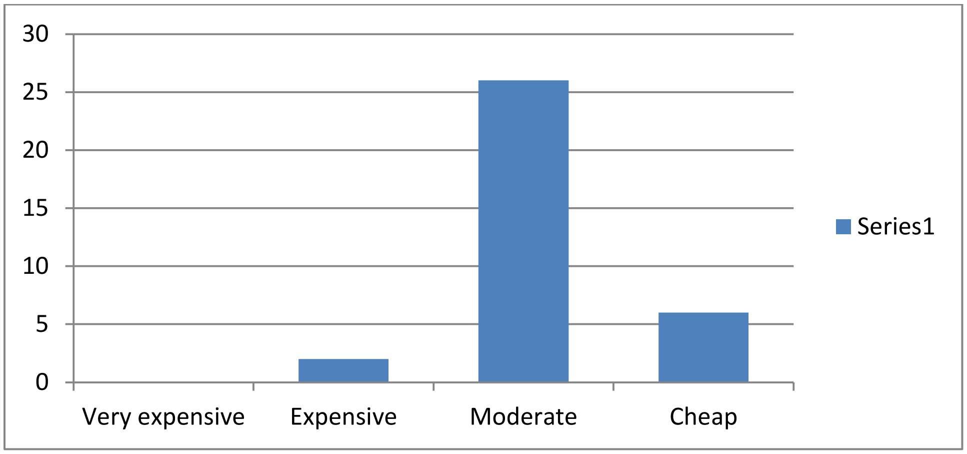


Figure 17: Opinion of residents on price of tap water

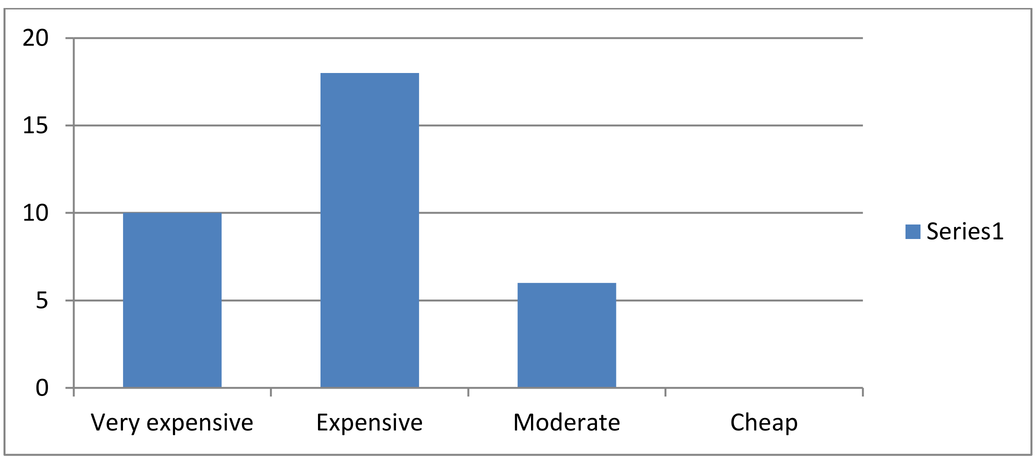


Figure 18: Opinion of residents on price of water they buy with buckets

This question was asked intentionally to know the price point of selling the recycled water, the residents are paying 15-20 birr for a single bucket (20 liters) of water and the tap water price is mentioned above therefor this result will help understand the resident's opinion on the current water price. The upper side figure shows the sample resident's opinion on the tap water price which shows no residents think it's expensive. On the lower side figure, it shows the sample resident's opinion about the price of water they buy in buckets.

Question 6: How do you describe yourself regarding water use?

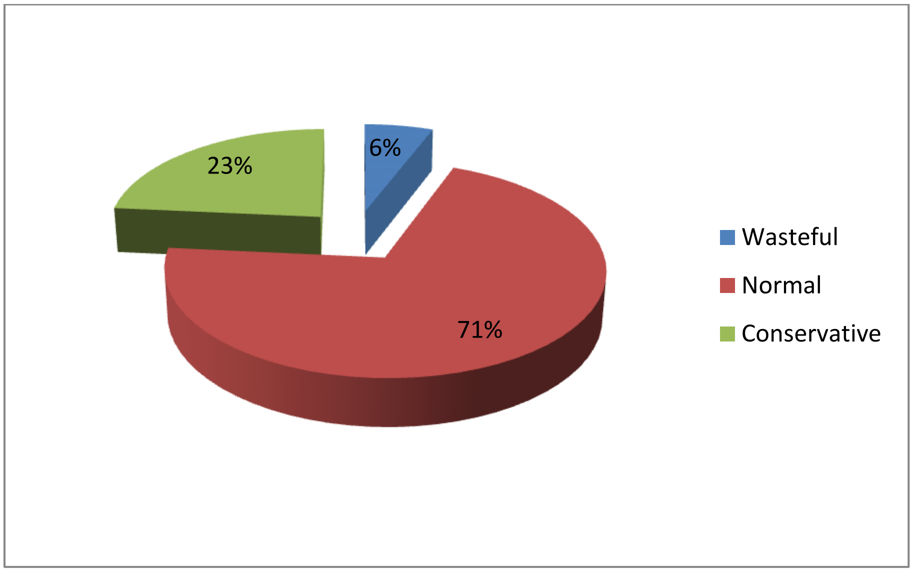


Figure 19: Opinion of residents on self-water using behavior

The result from this question shows that only 23% of the respondents consider that they are conservative in water utilization. On the other hand there are 6% of the people who thinks they are wasteful in water use. But the majority of the users 71% consider themselves as normal in water consumption. This shows People manage to use water they get carefully even though the amount of water they get is considerably small compared to other nation. And this is good information because people know how scarce and useful water is and will be willing to try new conservation ideas.

4.2 Water demand, greywater production rate and characterization of greywater

After analyzing the opinion of the residents about their water supply problem and their opinion about a greywater recycling system the next step is to calculate how much water does the residents need, and how much greywater will they produced.

4.2.1 Water demand in the condominium

Domestic water demand is the amount of water needed for drinking, food preparation, washing, cleaning, bathing and other miscellaneous domestic purposes. The amount of water used for domestic purposes greatly depends on the lifestyle, living standard, and climate, mode of service and affordability of the users.

Since the condominium we are studying is a residential only condominium the water demand is mainly domestic demand. There are many ways to calculate domestic water demand like water bill calculation method, manual water sheet method and many more but since there is an existing water shortage in the condominium using the above methods will lead to inaccurate result because most of them don't get tap water therefore water bill method will give us a very small demand result and the manual water sheet method will highly depend on the residents to note every single water use in the household, which will be very difficult to do in our context. Therefor we will rely on the study performed by AAWSA on the domestic water demand of Addis Ababa, the table below shows the daily indoor human water requirement for different use of activities including leakage assuming there is adequate water supply coverage.

Table 6: Domestic water demand in Addis Ababa

(AAWSA, 2019)

No	Use	Total Daily usage l/p/d
1	Toilet flushing	29.37
2	Cloth washing	23.87
3	Bath and shower	20.46
4	Kitchen	18.81
5	Leakage	15.07
6	Others	2.2
	Total	110

Therefore, the total average domestic water demand requirement per person has been calculated based on the Addis Ababa Water and Sewerage Authority target average per capital water consumption, 110 l/p/d.

$$Total\ daily\ water\ demand = Daily\ demand\ per\ capita \times Number\ of\ people$$

Since we have 70 people living in the study area that means
110 l/p/d$\times$ 70 p= **7700 liters per day** is the daily water demand in our study area.

The daily water demand changes with the season and days of the week. The ratio of the maximum daily consumption to the mean daily consumption is called the maximum day factor and usually varies between 1.0 and 1.3. (AAWSA, 2019) a maximum day demand of 1.1 is adopted for the city of Addis Ababa.

Considering the maximum day demand factor (= 1.1) the maximum daily demand of potable water required per house hold has been calculated
7700 l/c/d *1.1=**8470 l/c/d** is the maximum water demand in our study area (block -349)

4.2.2 The Amount of Greywater Produced and per Person and on the block

Based on the data from the table above, the amount of greywater produced can be determined. Viable greywater can be collected from cloth washing, bath and showers. The reason not to use kitchen as greywater is the water from kitchen sink have heavy organic matter and suspended solids and needs higher costs for treatment and also that toilet water accounting 26.7% of water usage or 29.37 l/c/d meaning that potable water used as toilet flushing would be eliminated. This means that 100% of the greywater produced can be used. Considering data on table 6 the amount of greywater produced per person and on the block that will be 44.3%=0.443 (greywater production factor) of the total water demand.

.

Therefore the **total daily greywater production** can be calculated by

$$= M\ Daily\ demand\ per\ capita \times greywater\ production\ factor \times Number\ of\ people$$

=110*1.1 l/c/d$\times$ 0.443 $\times$ 70

=3752.21 Liters is the maximum total amount of greywater production per day.

4.3 Characterization of the greywater generated from the building

After analyzing the opinion of the residents about their water supply problem and their opinion about a greywater recycling system, the amount of water demand in the condominium and the amount of greywater production from the condominium comes greywater characterization.

This step is very vital in the study process because the physical, chemical and Biological characteristic of the greywater will determine the type of treatment method we can use to bring the greywater to the standard we want that is toilet flushing water in our case.

4.3.1 Sampling of the greywater

Greywater sample was collected from the sampled households manually using plastic bottles because there is no separate plumbing for greywater and black water, the researcher and the building coordinator convinced the residents to pour samples of their wastewater from shower, waste water from cloth washing (machine and hand) and from the hand sink.

People were very cooperative, some residents gave water samples from their showers they collect when they shower some keep waster samples from *"mastatebya"* as a water sample for the hand basin, somp kept water samples arfter they wash colth using their hand and machine, some even unplug the plumbing of the hand basin to collect water samples as shown is the figure below.

Figure 20: sample household collecting greywater from hand basin directly

Figure 21: greywater samples from selected households

The samples from different households were taken to AASTU laboratory within 24 hours of production and mixed together before characterization.

Figure 22: Greywater samples being mixed before characterization

Samples were taken three times from the condominium one was on the regular weekday (24/12/2018 G.C), the other was on the weekend (05/01/2019) and the last one was token a day after the holiday (07/01/2019) (the holiday arrived during the time of the characterization stage and the researcher decides to take a sample thinking the greywater quality will be different).

The reason samples were taken from the households only three times was because of the financial constraints the research have. After the samples were taken to the laboratory they were kept in a 4 C^0 refrigerator measurement started.

pH

pH of the samples were measured directly using a multiparameter machine. The pH of a single sample was measured three times using the calibration of keeping a base line at a pH value of 4 in order to check the machine was working properly and the average of the three measurements was taken as the final pH of the sample.

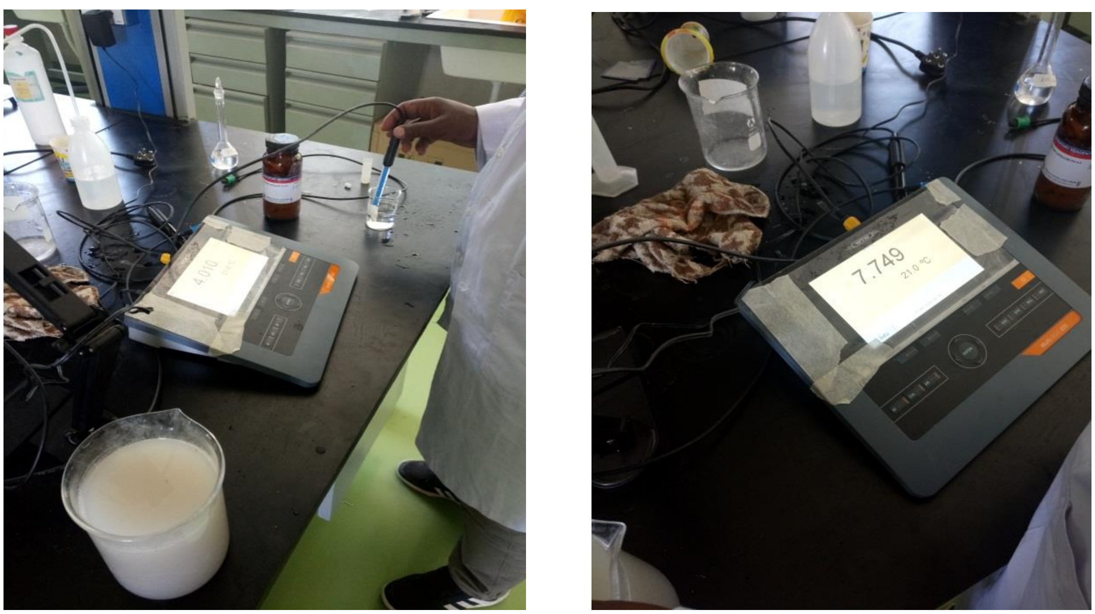


Figure 23: pH value being measured

Microbial content

Microbial content of the sample greywater was performed using Serial dilution method to calculate the microbial content of the samples, sterilization of distilled water was performed at 121 C^0 for 15 minutes then original sample was distributed at 10^{-1} 10^{-2} 10^{-3} 10^{-4} 10^{-5} in order to find a clear view of the microbs, then colony count was performed using the colony counter machine then then the total coliform was calculated using the formula as stated in chapter 4.

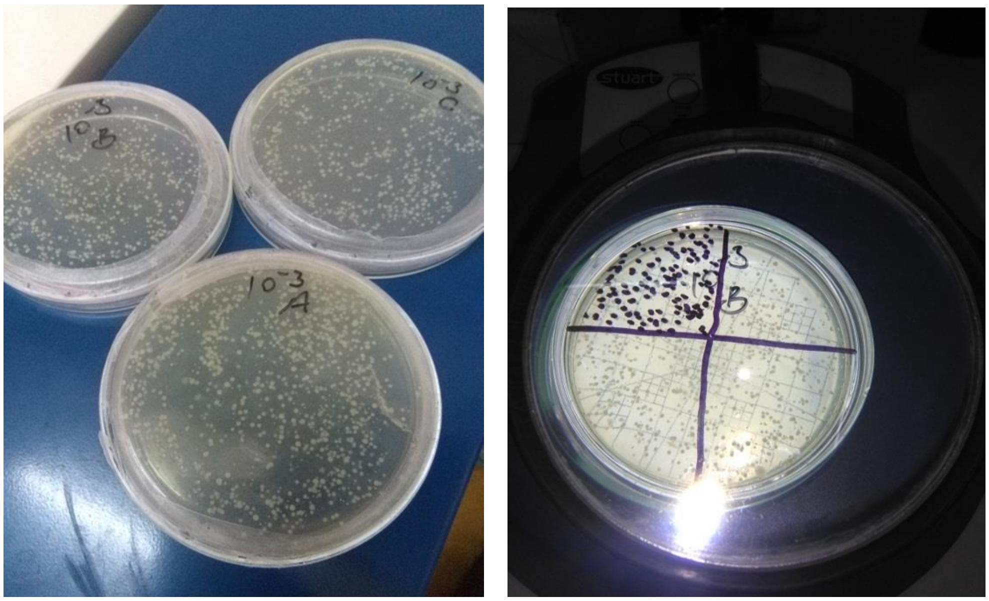


Figure 24: microbial content measuring in the laboratory

Dissolved oxygen

This was performed directly using the multiparameter machine we used for the pH, using the calibration of standard 6.0. A single sample will be measured three times, and the value of the DO will be recorded at the 30^{th} second of the detector inserted in the sample then the average of the measured value will be recorded as the final value of the sample.

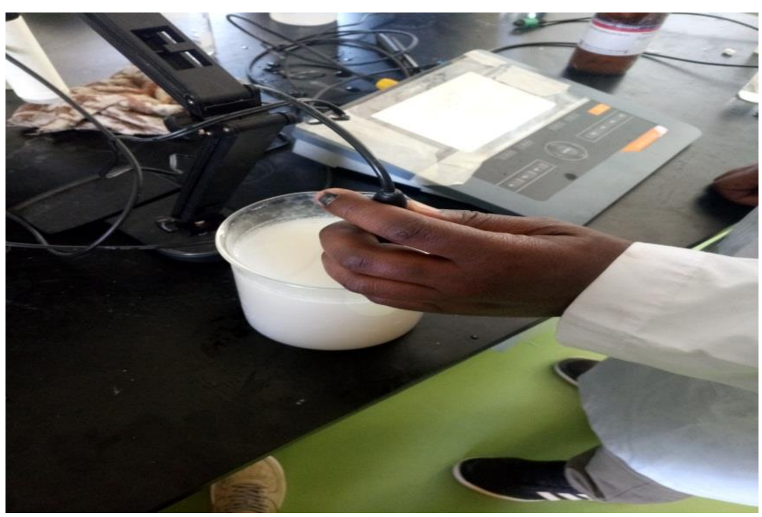


Figure 25: DO being measured using a machine

Total solid

Total solids are dissolved solids plus suspended solids in the greywater, it was calculated by using the formula stated on chapter 4, the temperature of the sample were dried at 180^0C for 2 hours before measurement, APHA 2540 C, procedure was followed during the procedure of measuring the total solid.

Total suspended solid

Total suspended solids is the dry weight of the suspended particles that are not dissolved, this suspended solids was trapped by a filter and then were dried at 103^0C -105^0C before measurement. APHA 2540 D, was followed during the procedure.

Total dissolved solid

This will be calculated using a simple subtraction of the total suspended solid from the total solid amount of the sample.

Biological oxygen demand (BOD_5)

Biological oxygen demand is the amount of dissolved oxygen needed by aerobic biological organisms to breakdown organic material present in a given water sample, the standard incubation test period of 5 days at 20^0C. APHA 5210 B standard and procedure were followed.

Chemical oxygen demand (COD)

Chemical oxygen demand is an indicative measure of the amount of oxygen that can be consumed by reactions in a measured solution. APHA 5220B, open reflux method was followed to conduct and measure the COD.

Table 7: Characterization result of the greywater from the condominium

No	Parameters	Unit	Sample1 (week day)	Sample2 (weekend)	Sample3 (holiday)
1	Biological oxygen demand(BOD_5)	mg/l	299.8	315.06	384.21
2	pH		7.88	8.13	7.91
3	Total solid(TS)	mg/l	1250	2150	2496
4	Total Suspended solid(TSS)	mg/l	245	292	341
5	Total volatile solids(TVS)	mg/l	1420	1620	1247
6	Total dissolved solids(TDS)	mg/l	1005	1858	2155
7	Dissolved oxygen(DO)	mg/l	2.1	3.05	2.96
8	Chemical Oxygen demand(COD)	mg/l	682	748	720
9	Microbial content	CFU	$2.4*10^4$	$2.61*10^4$	$2.89*10^4$

As the result shows the effluent greywater does not meet the standard(table 5) to be reused again without treatment, the main cause of for these impurities are that the greywater forms a complex bond since it contains hair, fat, oil, grease, mucus, soap and detergent residue. Therefore one method has to be incorporated to bring all this impurities down to the standard and make the greywater reusable for toilet flushing purpose. In order to choose a method which will be suitable for our case a number of factors has to be considered.

4.4 Results from interview of experts and stakeholders

After analyzing the opinion of the residents about their water supply problem, their opinion about a greywater recycling system the, how much water does the residents need, how much greywater will they produced and what are the characteristics of the greywater the next step is to design a treatment method which will bring the quality of the greywater to the standard considering other factors like cost, land space required and other things. Developed countries have their own standards and framework on what factors to consider when designing a greywater recycling system divided in different zones but in Ethiopia such framework doesn't exist, therefore we have to develop our won standard using literature review and interview with experts to make it fit our status. So this interview was conducted to develop such a standard in this study.

The interview was held with many stakeholders, the first of which were few residents who were interested in the study, who have educational background to discusses the plan scientifically and they are also influential in the building which means they know how and what the other the resident's perspectives toward new ideas. The remaining interviewees were Engineers and experts from different governmental institutions (AAWSA, EPA (Ethiopia), AAHCPO) who have in depth knowledge about the study area and currently working in designing, distribution management & environmental protection departments.

In total 14 experts were involved in the interview among whom 3 of them were residents at the condominium these residents were chosen for the interview because they took the time to read about the research area after they were given the questionnaire and they also have the educational background the influence in the block so that interviewing them will give a very huge advantage for the study. In addition to the residents 4 Engineers from AAWSA who works in planning and distribution department were also selected for the interview, because they are working on planning a water supply strategies for the new condominiums and were considered they closer to the case than their other work colleagues. Other experts who were involved in the interview were 3 Engineers from AAHCPO who specifically work in the design department and selected based on their different specialties (Sanitary design, Structural design and architectural design) in order to get a full expert opinion on the case. The last interviewees were 4 experts from EPA, who works in urban environmental protection department.

It has to be noted that the questionnaire includes an open ended questions which is not answered by yes or no answers because the intention of the interview was getting in depth relevant data on issues like whether there is sufficient water supply for condominium houses, the advantages and disadvantages of greywater recycling, advantage and disadvantages to collecting greywater through separate plumbing, public opinion for the acceptance of greywater recycling, existing greywater treatment technologies and the consideration to be under taken for the selection of greywater technologies.

Concerning whether there is sufficient water supply for condominium houses the interview result from this question shows that 100% of the respondents answered there is no sufficient water supply for condominium houses because of technical problems of the sub ground water pumps, the dwindling ground water supply, failure in the water pipe lines, problems on quality of ground water, Insufficient foreign currency to start new projects.

Regarding the advantages and disadvantages of greywater recycling; the advantages of greywater recycling for toiler flushing from the interview result shows; the recycling has an advantage to full fill the gap between the supply and the gap demand of water in condominium up to 33%. The disadvantages of greywater recycling from the interview result shows; 100% responses the biggest disadvantage of greywater recycling technology is high construction and running costs, 31% responded the land space required to construct such projects can cause big troubles, 16% thinks the disadvantage of greywater recycling system is the accessibility of the technology and 21% fears the system will face a low social acceptability because of the quality and health related issues, and claiming people do not respond to new systems quickly.

Regarding the advantage and disadvantages of collecting greywater through separate plumbing of black water and greywater; the interview result shows; 96% says it is easy to use the method to collect the greywater, in addition to that 60% of the experts mentioned separate plumbing is also easy for maintenance. On the other hand the disadvantages of collecting greywater using separate plumbing the interview result 28.57 shows 50% the experts think it have an additional cost of sanitation construction and 50% of the experts don't think there is no disadvantage on separate plumbing.

Regarding positive public opinion for the acceptance of greywater recycling the interview result from this question shows that 60% of the respondents answered there will be a positive public opinion for the acceptance of greywater recycling because of shortage of water in the town, where as 40% of the respondents answered there is a negative public opinion for the acceptance of greywater recycling because of lack of awareness and fear of the quality of the recycled water.

Regarding the design consideration which needs to be given emphasis during the design of the greywater recycling system for toilet reuse was collected from the experts using a rating method then comparison matrix was conducted to give each section a weight, the result is tabulated as follows.

Table 8: Comparison Matrix Criteria Weighing factors **(Department, 2015)**

No	Design Criteria	Criteria Weighing factor
1	Land space required for construction	10%
2	Initial investment and running costs	35%
3	Environmental protection(health related factors)	12%
4	Quality of the greywater to be treated	12%
5	Skilled man power required to design, construct and maintain the system	23%
6	Familiarity of the technology to the residents	8%

4.5 Comparison of the Alternative Options

After the above result from the interview with experts the comparison was made on this research additional literature review and the personal opinion of the researcher, this was considered as a limitation of the study as well because developed countries have a specific comparison guide set out for residential, commercial and other buildings based on their location (urban or rural), but the researcher couldn't find such a framework or guide in Ethiopia therefore the comparison method was based on the above governing factors focused on the quality of the greywater to be treated, land space required for construction, protection of the environment (the public health), skilled man power required to design, construct and maintain the system, the familiarity of the technology to the residents and the relative initial and running cost of the treatment technologies for reusing of greywater for mass condominium houses.

Therefore, the implementation of a Multi-Criteria Analysis (MCA) would be the appropriate method for the all-embracing comparison of the alternative treatment options. standard feature of MCA is the "performance or evaluation matrix" in which each column describes a "treatment option" (technology) and each row describes a "criterion" against which the performance of each option is evaluated. Such a matrix is developed for the evaluation of the alternative treatment options under consideration. In order to assess "the performance of each options for the set of the developed criteria numerical scoring is applied with a scale 10 to 35, 35 being the maximum point to allow the importance of the criteria to be differentiated and it is selected based on the researchers feeling. Scores are summarized with weighting factors and summed up to give a total score. The MCA approach that applies scoring and weighing is a compensatory MCA technique since low scores on one criterion may be compensated by high scores on another, therefore we will compare treatment systems mentioned in chapter 2 based on the above design criteria's.

1. Comparison based on "Land space required for system construction"

Table 9: Comparison based on Land space required for system construction

	Criteria	Criteria weighing factor	Types of treatment technologies and their weighing score (WS)								
			CAS	EAAS	SBR	TF	RBC	WSP	MBRR	MBR	PGTS
			WS	WS	WS	WS	WS	WS	WS	WS	WS
1	Land space required	10%	6	4	7	8	9	4	9	10	7

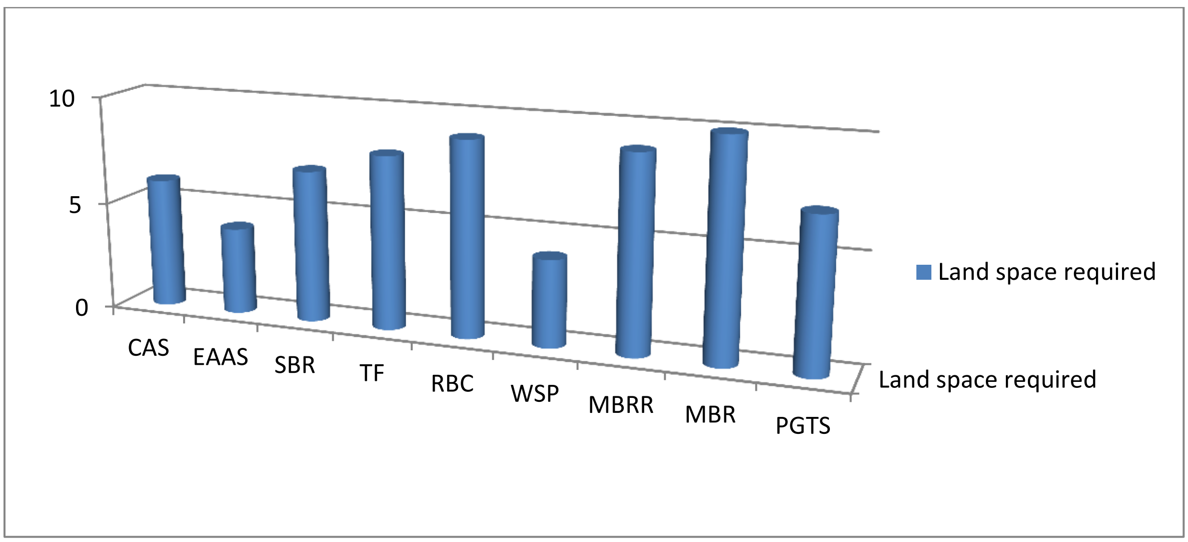


Figure 26: Ranking based on "Land space required for system construction"

As the result showed above the most appropriate treatment method of technology considering low land space required for construction is MBR which has high scores and the second higher score in place comes MBBR. Again WSP and EAAS systems found at the bottom of the ranking, due to higher land requirement.

2. Comparison based on "Initial investment and running costs"

Table 10: Comparison based on "Initial investment and running costs"

	Criteria	Criteria weighing factor	Types of treatment technologies and their weighing score (WS)								
			CAS	EAAS	SBR	TF	RBC	WSP	MBRR	MBR	PGTS
			WS	WS	WS	WS	WS	WS	WS	WS	WS
1	Land space required	35%	30	30	31	32	33	34	29	30	31

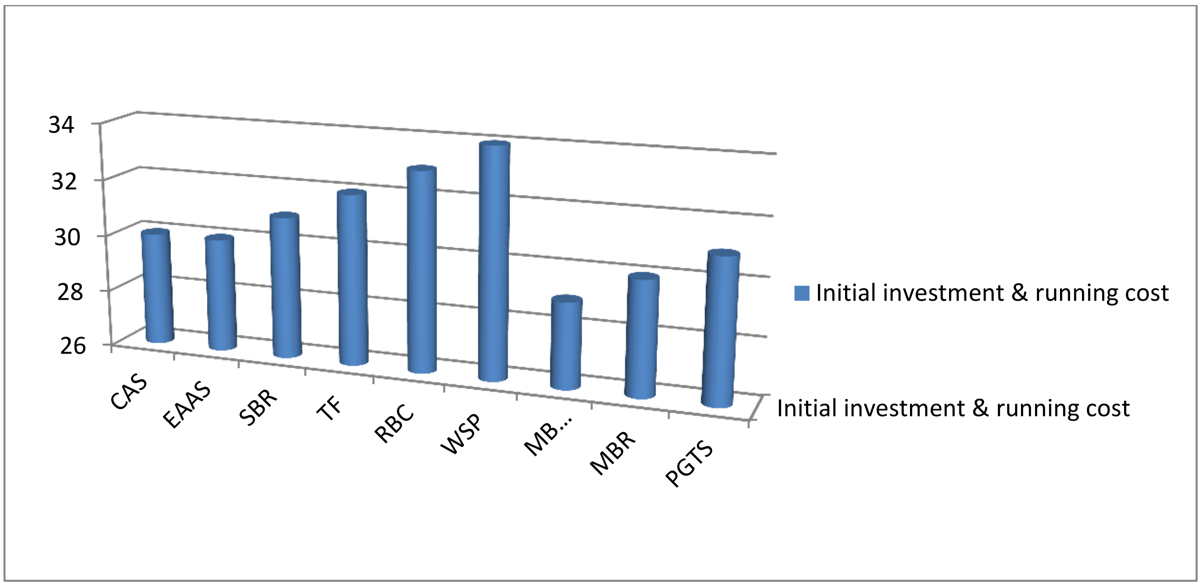


Figure 27: Ranking based on "Initial investment and running costs"

As the above graph showed the most appropriate treatment method of technology based on the relative investment and running costs is PGTS and second in place comes WSP.

Again MBR and MBBR systems found at the bottom of the ranking, due to higher investment and running costs.

3. Comparison based on "Environmental protection (health related factors)"

Table 11: Comparison based on "Environmental protection (health related factors)"

	Criteria	Criteria weighing factor	Types of treatment technologies and their weighing score (WS)								
			CAS	EAAS	SBR	TF	RBC	WSP	MBRR	MBR	PGTS
			WS	WS	WS	WS	WS	WS	WS	WS	WS
1	Environmental protection(health related factors)	12%	8	9	10	6	7	5	11	12	8

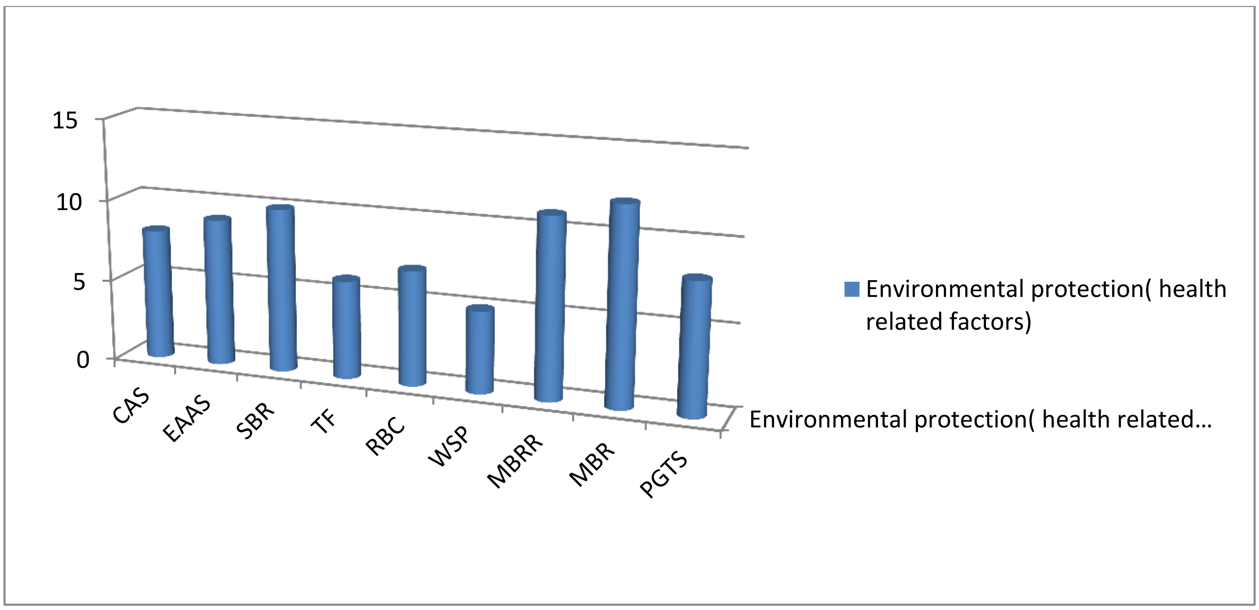


Figure 28: Ranking based on "Environmental protection (health related factors)"

As the result above showed the most appropriate treatment method of technology based on the protection of the environment (the public health) and odor nuisance is MBR and second in place comes MBBR. Again WSP and TF systems found at the bottom of the ranking, due to higher influence based on the protection of the environment (the public health) and odor nuisance.

4. Comparison based on "Quality of the greywater to be treated"

Table 12: Comparison based on "Quality of the greywater to be treated"

	Criteria	Criteria weighing factor	Types of treatment technologies and their weighing score (WS)								
			CAS	EAAS	SBR	TF	RBC	WSP	MBRR	MBR	PGTS
			WS	WS	WS	WS	WS	WS	WS	WS	WS
1	Quality of the greywater to be treated	12%	7	6	10	5	4	8	9	12	10

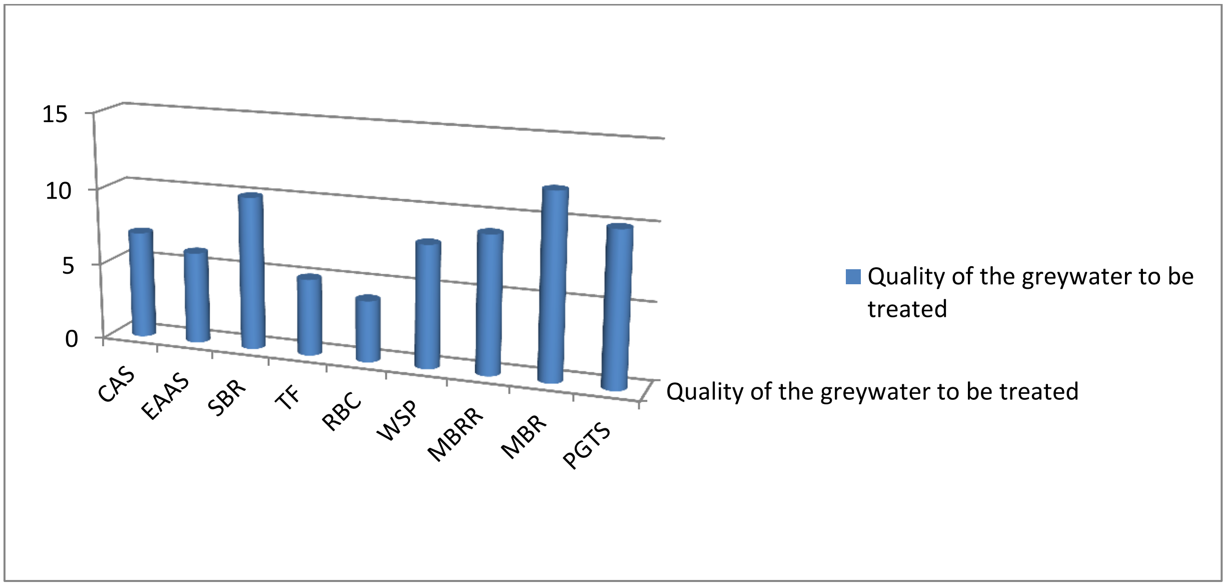


Figure 29: Ranking based on "Quality of the greywater to be treated"

As we can read from the above chart the most appropriate treatment method of technology considering the quality of the greywater to be treated is MBR and second in place comes SBR & PGTS. Again RBC and TF systems found at the bottom of the ranking, due to low effluent quality.

5. Comparison based on "Skilled man power required"

Table 13: Comparison based on "Skilled man power required"

	Criteria	Criteria weighing factor	Types of treatment technologies and their weighing score (WS)								
			CAS	EAAS	SBR	TF	RBC	WSP	MBRR	MBR	PGTS
			WS	WS	WS	WS	WS	WS	WS	WS	WS
1	Skilled man power required	23%	19	20	16	17	18	20	17	16	20

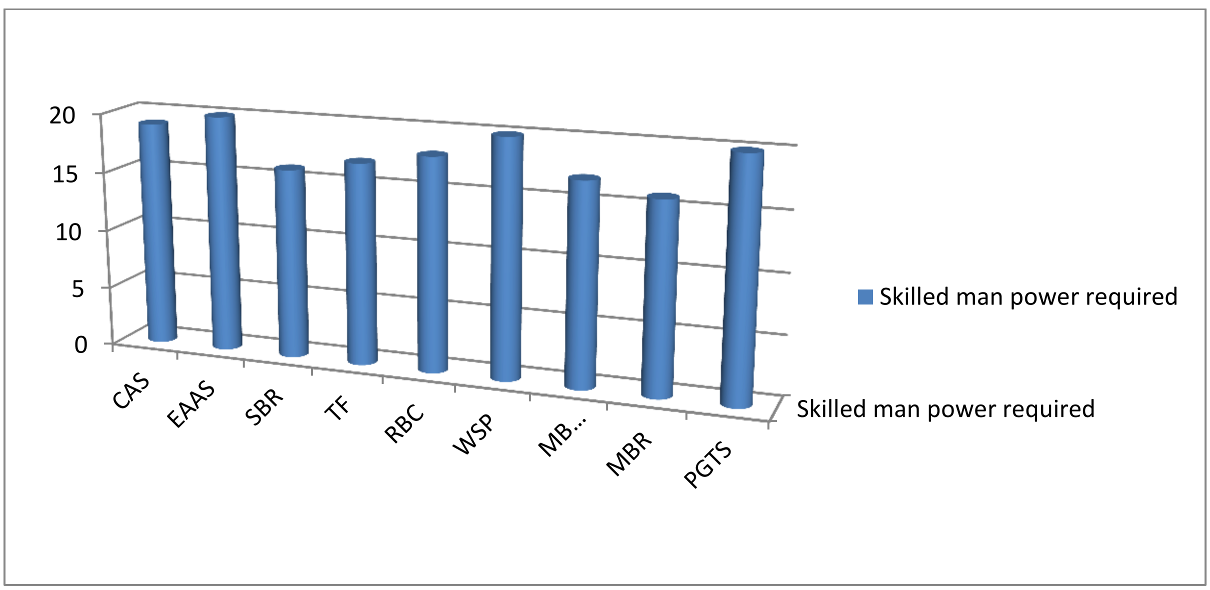


Figure 30: Ranking based on "Skilled man power required"

As the above result shows the most appropriate treatment method of technology based on the Personnel skills required is PGTS, EAAS & WPS and second in place comes MBRR and MBR systems found at the bottom of the ranking, due to higher personnel skills required to design, operate and maintain the system.

6. Comparison based on "familiarity of the technology in the residents"

Table 14: Comparison based on "familiarity of the technology in the residents"

	Criteria	Criteria weighing factor	Types of treatment technologies and their weighing score (WS)								
			CAS	EAAS	SBR	TF	RBC	WSP	MBRR	MBR	PGTS
			WS	WS	WS	WS	WS	WS	WS	WS	WS
1	Familiarity of the technology to the residents	8%	7	7	3	4	3	8	7	4	7

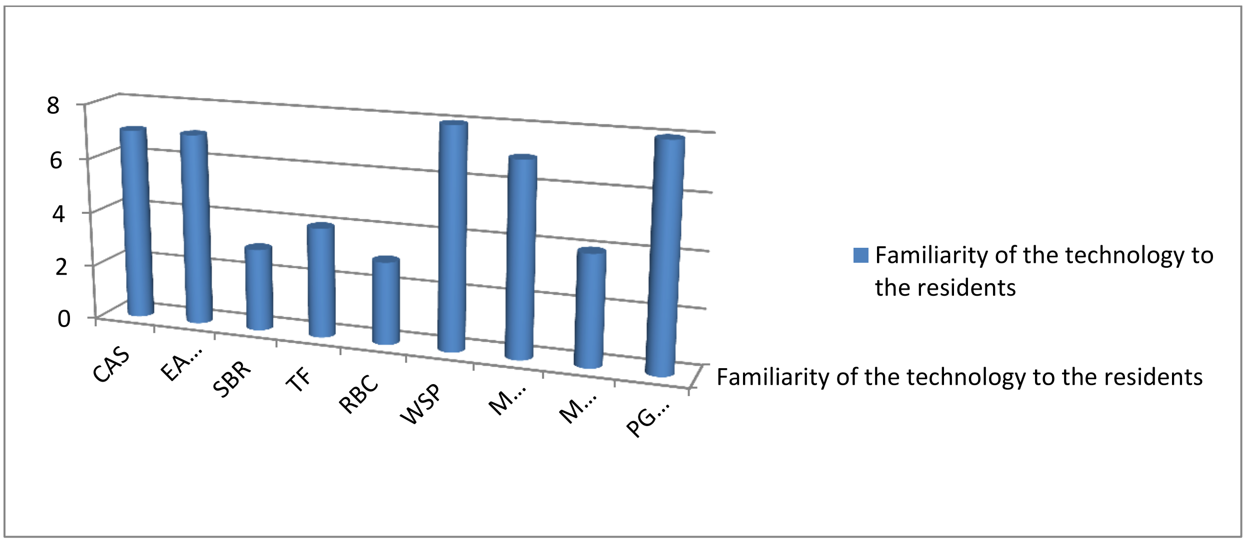


Figure 31: Ranking based on "familiarity of the technology in the residents"

As presented above the most appropriate treatment method of technology based on the familiarity of the technology in the city is WPS and second in place comes CAS, PGTS and EAAS. Again SBR, RBC, MBBR and MBR systems found at the bottom of the ranking, due to unfamiliarity of the technology to the residents.

Table 15: Summary of Scores from the Comparison of Different Alternative Options

No	Design Criteria		CAS	EA AS	SBR	TF	RBC	WSP	MBR R	MBR	PGTS
		W.F	W.S	W.S	W.S	W.S	W.S	W.S	W.S	W.S	W.S
1	Land space required for construction	10%	6	4	7	8	9	4	9	10	7
2	Initial investment and running costs	35%	30	30	31	32	33	34	29	30	31
3	Environmental protection(health related factors)	12%	8	9	10	6	7	5	11	12	8
4	Quality of the greywater to be treated	12%	7	6	10	5	4	8	9	12	10
5	Skilled man power required to design, construct and maintain the system	23%	19	20	16	17	18	20	17	16	20
6	Familiarity of the		7	7	3	4	3	8	7	4	8

	technology to the residents	8%									
	Total	**100%**	**77**	**76**	**77**	**72**	**74**	**79**	**82**	**84**	**84**

The comparison based on the six comparison criteria assumptions the study reflects the best possible treatment technology from the evaluation of the treatment options are MBR and PGTS second in place comes MBBR systems. Again TF and RBC systems found at the bottom of the ranking, due to these six comparison criteria assumption and evaluation.

From the comparative selection of various available greywater treatment technologies above; It has to be noted that the comparative analysis of various available decentralized greywater treatment technologies were selected and compared based on an interview results and literature review as stated by the comparative criteria's and its weighting factor. Hence, the discussion of the findings from the selection of greywater treatment technologies is presented below.

Based on the comparative analysis Membrane bio-reactors an Personalized Greywater treatment systems stand out from the others, that is because of the fact that the MBR can deliver a higher quality of effluent than the rest of the other methods and PGTS rise out from the others because of the cheaper cost and the no need of much skilled worker.

Based on the above result a system design was made and one PGTS method was selected to be experimented on lab-scale experimentation. As it is widely discussed in the next chapter.

This comparative analysis of various available decentralized greywater treatment technologies was performed solely based on literature review (previous case studies) and interview results with experts therefore the research study has a limitation and needs detailed study and different experimentations for prioritizing and deciding the most appropriate decentralized greywater technology for Addis Ababa condominiums.

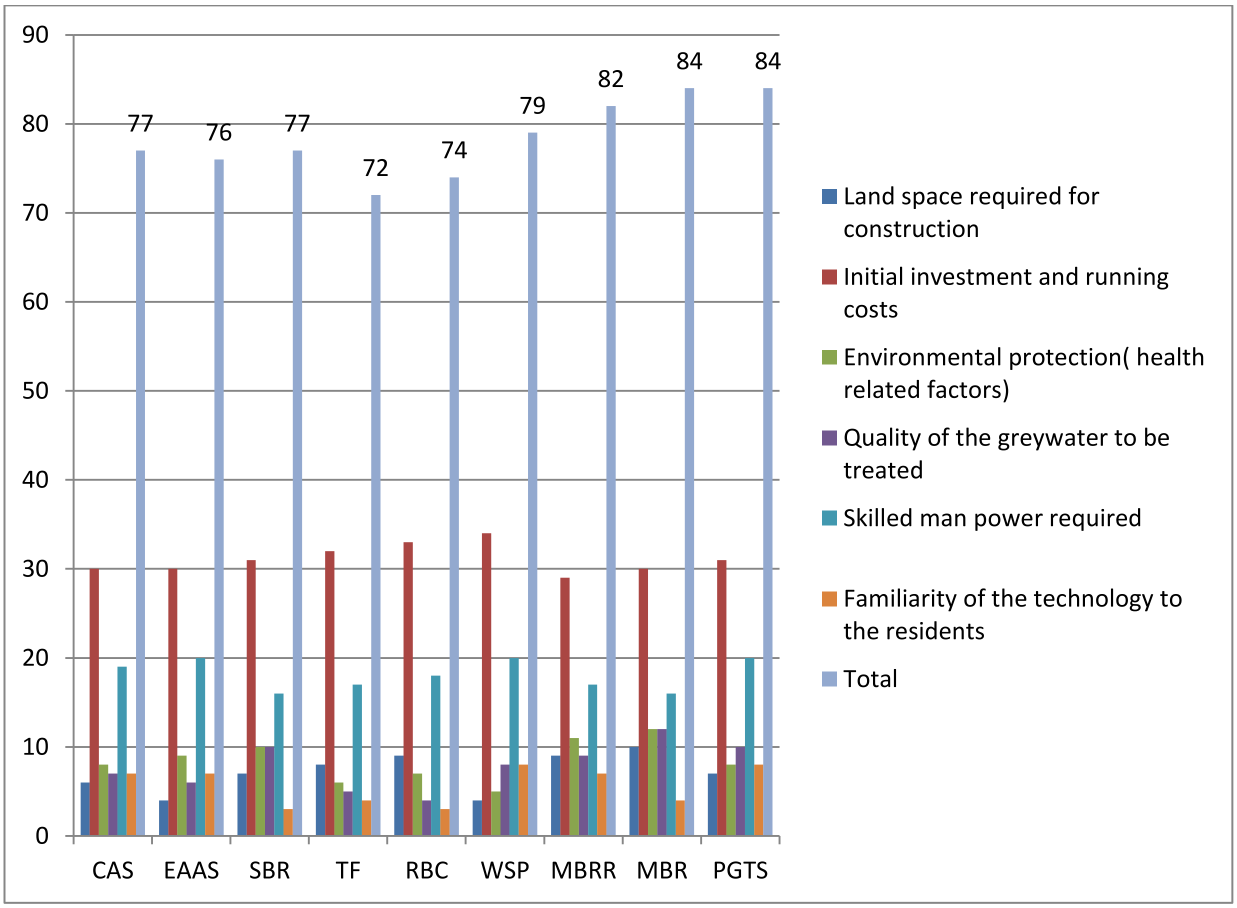


Figure 32: Summaries Scores from the Comparison of the Alternative Treatment Technologies

CHAPTER 5

5. System design for greywater treatment

Design requirements

Greywater sufficient to meet the demand shall be collected in a separate drainage pipework and allowed to flow from collection appliances to the greywater treatment system via gravity or symphonic action. Surplus greywater shall be collected and discharged directly to the sewer. The design of the existing sewerage system and the sewerage master plan for the district should accordingly take into account the abstraction of greywater from the sewerage system and make appropriate adjustments to the design assumptions so as to safeguard the self-cleansing capacity of the foul sewer and the overall capacity in the new system, especially during the early stage of occupation where the flow rate of sewer is low. In case the self-cleansing capacity cannot be maintained due to low flow rate, greywater collection system shall be suspended until the flow rate reaches the required level for self-cleansing. Then finally the distribution system will be designed. (Department, 2015)

5.1 Greywater collection, treatment and distribution design

5.1.1collection method

Separation of greywater and black water is achieved through separate plumbing; the greywater and black water led through the house hold in separate sewage systems making a separate treatment possible as shown in the figures below.

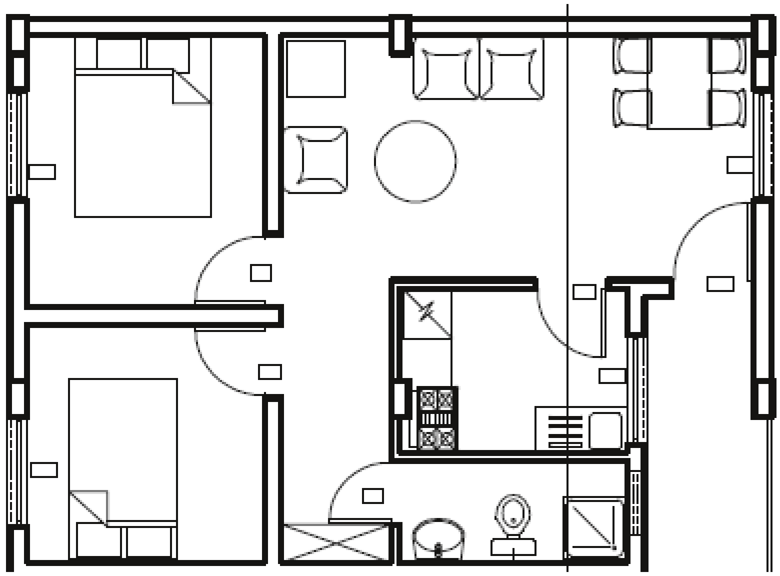


Figure 33: Typical floor plan of a two bed room condominium

The main problem in this stage will be the reconstruction of the plumbing installation, as discussed on the socio-technical chapter some residents are not open to any kind of construction inside their house even if they are suffering from the lack of water, the main source of this unwillingness surveyed comes from the lack of trust the residents have towards the authorities, they informed the researcher that they received the houses without any finishing works even though they are paying for a price of a house fully finished, therefore they had to spent a significant amount of money to do the finishing up work of the house and they are unwilling to see that being destroyed.

With the above concern on hand the plumbing installation needs be changed in to two separate plumbing units:

Plumbing-A: Collects water from hand basin, shower, and an empty closing hole needs to putted in the in the toilet room so that whenever people buy washing machines they can easily plug the waste drain pipe to the wall hose which will enter the greywater collection system.

Plumbing-B: Collects water from the kitchen sink and the toilet, this will get transferred to the municipal sewerage system.

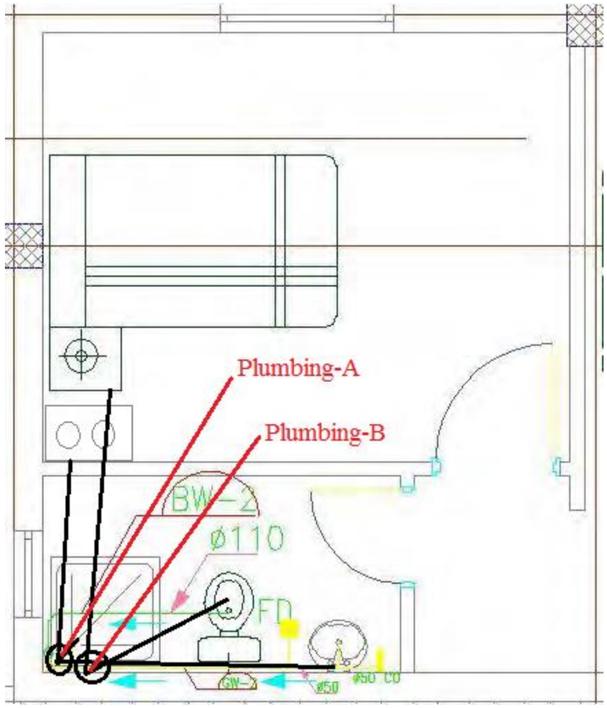


Figure 34: Two different waste water plumbing installation

The size of both plumbing types will be 50$^{\Phi}$ mm inside the house and the main receiver will be 250$^{\Phi}$ mm.

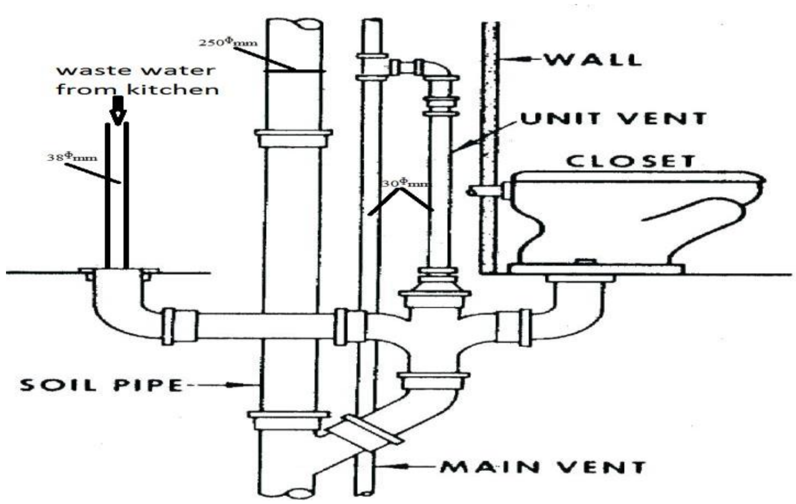


Figure 35: Plumbing-B installation

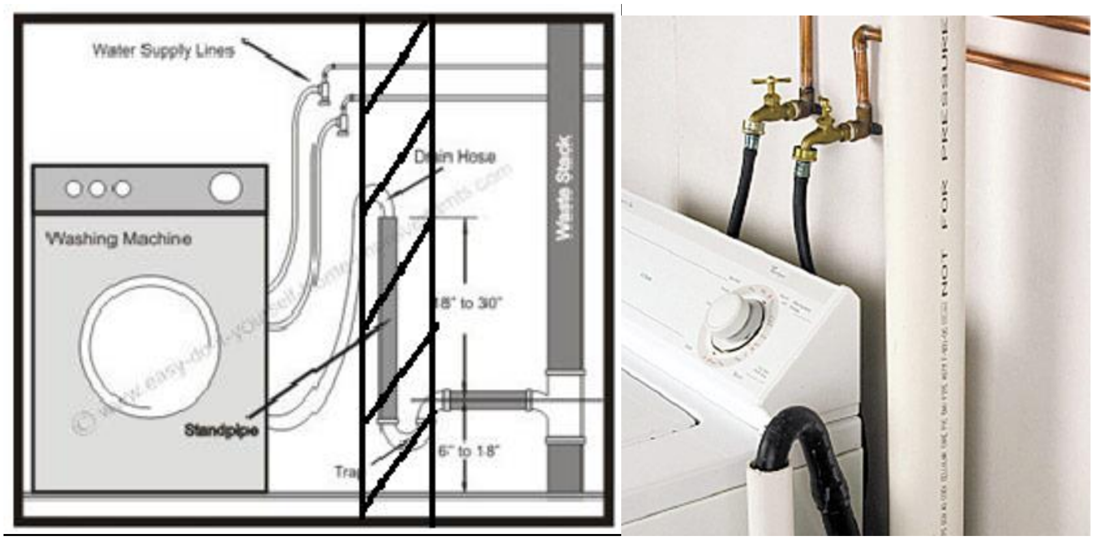


Figure 36: Plumbing-A Hose inbuilt in the wall for washing machine drain

The need to integrate a 38mm diameter on the wall is because we understood from our survey that 87% of the sample residents said they spill their laundry waste water in the toilet which can be a huge negative factor in the amount of greywater production, therefor installing this hose will eliminate this problem.

Additional points which will be addressed during the construction of the collection method are

- To reduce the generation of foam, the greywater collection pipework should be designed to minimize turbulence and the use of bends. It should be free draining to avoid stagnation. Suitable non-intrusive type of flow measurement devices should also be used to avoid blockage. (Department, 2015)
- A bypass shall be installed around the greywater system allowing the collected greywater to flow directly to the sewer during periods of maintenance or system isolation. The bypass shall not tie into the storm drain system (Department, 2015)
- Due to water quality concerns from bacterial growth, collection systems should be designed and constructed such that greywater reaches the treatment process as soon as possible. Intermediate storage should be avoided. (Department, 2015)

- Flow measuring device(s) shall be provided to measure the quantity of total greywater collected (Department, 2015)

5.1.2 Pre-screening

Pre-screening is a technique used to decrease the load on the screening structure, this can be performed by putting a well-designed screens on the hand basin and on the shower drain, as you can see in the picture below, the left side screener can be easily installed in hand basins to trap large sized particles from entering the system, the right side picture shows one of the simplest yet very effective shower hair trap screener.
Pour size less than or equal to 2mm of both screeners should be used as pre screener.

Figure 37: Example of best pre screeners

5.1.3 Collection Tank

Considerations before designing the collection tank according to (Department, 2015) are:

- The collection tanks for greywater storage systems should be constructed of plastics, such as glass-reinforced polyester (GRP) or high-density polyethylene (HDPE). Collection tanks may also be constructed of concrete or steel if these are suitably sealed and protected against the corrosive effects of the stored water. Tanks should be lightproof to minimize algae growth.

- Collection tanks should be fitted with a close-fitting, removable cover to allow for periodic inspection and for internal cleaning and maintenance of components such as sensors and submersible pumps. Providing a lock to the access cover is recommended to avoid accidental entry into the tank.
- The tank should be sited so that the stored water does not attain high temperatures that could encourage microbial growth. Above ground tanks should be opaque to minimize the potential of warming and algae growth.
- The sewage backflow prevention device should be fitted with a visible indicator which may only be reset by manual intervention. The sewage backflow prevention device can be in the form of a valve and a float-operated backflow detection switch in the vertical connecting pipe to the foul drain or sewer.
- The greywater storage tank should be designed to store untreated flow for a period of at least two hours, but no more than twenty-four hours. For most applications, the tank may be sized to provide 8 to 10 hours of storage.
- Greywater collection tanks shall overflow to the sewer system. In addition, a drain is required at the bottom of the collection tank to allow solids that have settled out of the greywater to be collected into a sludge storage tank.

Estimating greywater yield

Calculating the daily demand have two methods

1. Using greywater yield table
2. Using exact data

We have the average l/p/d of greywater production of greywater in the condominium and we have the exact number of people living in block-349 multiplying both number will give us the daily yield of the block.

Total Daily Yield= daily production per person* number of population

Total Daily Yield= =110*1.1 l/c/d$\times 0.443 \times 70$

Total Daily Yield=3752.21 liter/day

If we take a look at the greywater yield for Residential $R1^1$zone (Department, 2015)

Residential $R1^1$= Private/Public housing blocks in R^1 zones: Private Sector Participation Schemes and Housing Authority Home Ownership Schemes. Residential One (R1) is the highest density residential planned use. Population densities may be around 1,740 persons per hectare (Department, 2015)

Greywater yield per person = 90 l/p/d

Total daily yield= daily production per person* number of population

Total daily yield=90l/p/d*53p

Total daily yield=4770 liter/day

**Since the greywater yield increases with the availability of water, it is better to take 4470l/d in order to be safe.

Calculating size of the tank

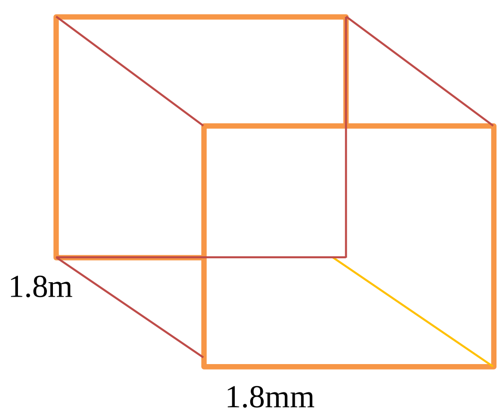
Therefore 4470liter/day=4.47 m^3/day

L*W*H=4.47 m^3

L=1.8m

W=1.8m

H=1.8m



15 cm was added to each side of the tank in order to take a safety precaution (Department, 2015) for over flooding and sludge accumulation. The material to construct the tank can be chosen from the above listed options.

Estimating treated greywater demand

Volume per user=volume peruse(liter)/use factor

Easy way to determine use factor is using the estimation table. (Department, 2015), therefore since the intended use of the recycled water is for toilet flush,

Use factor=4.42

Volume per user= 90 l/p/d /4.42

Volume per user=20.36 l/p/d

Total treated greywater demand= 397.8 l/p/d *53 p **= 1079.08 l/d =1.079m^3/day**

7.1.4 Greywater Treatment

Greywater treatment shall consist of the following components:

(a) Pre-treatment & Filtration

(b) Biological treatment

(c) Disinfection

Since we have found the MBR & PGWT are the two treatment methods which stand out on the comparative analysis, it was decided to do the system design for the MBR and a lab-scale experiment for one of the PGWT methods.

Therefore the treatment method chosen here for the system design was **MBR.**

Design considerations on designing treatment method. (Department, 2015)

- Pre-treatment shall include a fine/mesh screen to remove hair, soap, and other particulate matter in the greywater. The screen shall have a spacing of 2 mm.
- Filtration shall be included and shall be able to meet the required effluent turbidity of equal or less than 5 NTU. Many types of filters are commercially available, including sand and mechanical. Membrane filtration, such as microfiltration (MF) and ultrafiltration (UF) may also be used in place of the conventional filters. They are capable of achieving high effluent quality standards on a small footprint
- Where greywater is collected from kitchen sinks and dishwashers, pre-treatment shall also include an oil and grease trap. An automatic oil and grease trap, where

the oil is skimmed out automatically using a timer or sensor mechanism, shall be used.(Does not apply to our case)

- Flow measuring device(s) shall be provided to measure the total quantity of all greywater treated.
- The membrane bioreactor (MBR), a hybrid treatment process that combines biological treatment and membrane filtration into one system, may be used in place of the biological and filtration components.
- Disinfection may utilize chlorine disinfection which may be achieved by using a sodium hypochlorite system. Chlorine tablets may be used for smaller systems. A separate disinfection contact chamber of a size to allow a minimum of 30-minute contact time at peak flow for disinfection is required
- Alternatively, for small scale systems (daily consumption <5m3), the chlorine supplement can be provided by using household bleach. Common household bleach contains about 5.25% sodium hypochlorite solution which is equivalent to approximately 20mg of chloride ion per liter. Household bleach can be mixed into the reclaimed water at a ratio of 1:20000, i.e. 50ml of household bleach per 1 m^3, or 1000 litre, of reclaimed water to supplement the required level of residual chlorine. Field testing shall however be conducted to determine the exact ratio for correct dosage
- The treatment system shall be capable of connection to the sewer such that:
  A. An overflow to the environment will not occur should there be a failure of the treatment system.
  B. The operator may direct greywater to the sewer during periods of rain or other circumstances adverse to the discharge of treated greywater into the reuse distribution system.
- The treatment system shall be clearly marked with the brand name, model, and month and year of manufacture which should be clearly visible after installation.
- All metal components shall be of stainless steel or other non-corroding material unless adequately protected against corrosion to satisfy the service life of the component.

- Unless specifically designed to operate in a submerged condition, all mechanical and electrical equipment when located within the treatment system vessel(s) shall be located above the maximum water level of the treatment system.

(a) Pre-treatment and filtration

The MBR system requires the level of preliminary and primary treatment applied in CAS systems. It also requires additional micro-screening (0.5-2mm depending on the type of the membranes) upstream of the bioreactors in order to protect the membranes from clogging and from damage from coarse objects.

The membranes are of three types in terms of their architecture, namely the hollow fiber, the flat sheet and the wound type. Also, according to the level of filtration membranes are categorized as Micro-filtration (MF, with pore size 0.1-10μm) and as Ultra-Filtration (UF, with pore size 0.001-0.1μm). The most commonly used membranes in MBR systems are the hollow fiber and the flat sheet UF membranes.

(b) Biological treatment

A pre made affordable MBR brands are recommended for a long term efficiency (with guarantee and a shorter payback period than a self-manufactured membrane system, one system which meets all the above design criteria is a brand called biomicrobics.® more details about the product can be found on the link underneath.

http://www.biomicrobics.com/products/bio-barrier-membrane-bioreactor/biobarrier-greywater-treatment-system/

(c) Disinfection

Since the daily demand is under $5m^3$: the chlorine supplement can be provided by using household bleach. Common household bleach contains about 5.25% sodium hypochlorite solution which is equivalent to approximately 20mg of chloride ion per litre. Household bleach can be mixed into the reclaimed water at a ratio of 1:20000, i.e. 50ml of household bleach per 1 m^3, or 1000 liter, of reclaimed water to supplement the required level of residual chlorine. Field testing shall however be conducted to determine the exact ratio for correct dosage.

7.1.5 Distribution

Pumps: pump are needed to push the treated water to the top of the building so that it can flow to the toilet using gravity, choosing a pump should follow the following criteria's. (Department, 2015)

- The pumps should be corrosion resistant and properly selected to pump to the required head to fill the cistern or supply adequate flow if pumped directly to the point of use. Submersible pumps and external self-priming pumps are typical.(since we need a pump to push the water to the top of the building we need external self-priming pump)
- Pumps should be sized so that each pump is capable of overcoming static lift plus friction losses in the pipework and valves.
- Pumps should be selected and arranged such as energy use and noise are minimized, cavitation is avoided, and air is not introduced into the greywater and rainwater system.
- A non-return valve should be provided in the suction line to the pump to prevent the water column from draining down. The pump discharge should be supplied with an isolation valve.
- The pump control unit should operate the pump(s) to match demand; protect the pumps from running dry; protect the motor from over-heating and electric overload; and permit manual override.

Pumps should be protected from dry running. A low level switch in the collection tank should be used. To prevent overheating or burn out of the pump, the level should be set such that the pump does not continually switch on and off due to small and infrequent inflow of source water.

Matching all the criteria’s in the design, one of the best affordable pump for our study is a brand called, carver® more details about the pump can be found on the site underneath. https://www.callaghanpump.com/domestic-water-booster-pumps-systems/

Power Supply: The power supply shall be readily accessible but also guarded to ensure against inadvertent isolation or disconnection of electricity.

Back-up Water Supply: An alternative water supply, such as potable mains water supply, is required as a back-up water supply to supplement the reclaimed water. The back-up water supply may be introduced into the following:

A. The treated greywater storage tank
B. An intermediate storage tank prior to pumping to the reclaimed water distribution system

A treated storage tank was selected for this design, because it is more easier to maintain and control.

Distribution tanker dimension

Since the treated greywater demand is 1079.08 l/d =1.079m^3/day

Therefore the dimension the tank will be as follows if it is rectangular

H= 1.2 m

L=1.2 m

W=1.2 m

With 15cm added to each side a safety precaution, (Department, 2015) or should be tank which can hold a volume of 1.5-1.7 m^3 if circular. Circular is chosen in this case because it can save area in the roof top and still be stable at the same time.

In addition a float switch located inside the storage tank shall be used to activate the back-up water supply when the water level in the storage tank reaches a low level. The float switch shall turn off the back-up water supply at a pre-set level to leave space for incoming reclaimed water.

Backflow Prevention

To prevent reclaimed water from entering the potable mains water supply, the back-up water supply shall be fitted with a backflow prevention device, such as:

A. Type AA air gap
B. Type AB air gap

Type AA air gap (air gap with unrestricted discharge) means a non-mechanical backflow prevention arrangement of water fittings where water is discharged through an air gap into a storage tank which has at all times an unrestricted spillover to the atmosphere. The air gap is measured vertically downwards from the lowest point of the inlet discharge orifice to the spillover level.

Type AB air gap (air gap with weir overflow) means a non-mechanical backflow prevention arrangement of water fittings complying with Type AA air gap requirements, except that the air gap is the vertical distance from the lowest point of the discharge orifice which discharges into the storage tank to the critical water level of the rectangular weir overflow.

-*** Type AA is chosen for this design because it is much safer.

Overflow, Bypass, and Drainage:

- An overflow shall be fitted to all tanks or cisterns to allow excess water to be discharged. The overflow shall incorporate backflow prevention. An overflow fitted to aboveground tanks or cisterns shall be screened to prevent the ingress of insects and rodent.
- The overflow and any bypass of the greywater system shall be connected to the foul sewer.
- Any discharge to drain from the greywater system shall minimize the volume of foam introduced to the drainage system and shall be properly de-chlorinated.

- The discharge of any surplus greywater as well as backwash water shall be made at a location that would not overload the downstream carrying capacity of their respective receiving sewerage or storm drain systems

Controls: the control unit shall

- In the event of any system failure:
  - A. Alert the user by a visible or audible warning;
  - B. Ensure that the bypass directs untreated greywater to the foul sewer, and untreated rainwater to the storm sewer;
  - C. Ensure that greywater and rainwater treatment continue or that treated greywater and rainwater are not stored for a period that would allow water quality to deteriorate
- Control pumps and minimize operational wear and energy use

Sludge Holding Tank

- A sludge holding tank is necessary to provide temporary storage of sludge produced by the biological treatment component of the greywater treatment system.
- Wet sludge should be hauled off to the local municipal sewage treatment works on a periodic basis.
- The sizing of the sludge holding tank depends on the biological process and influent characteristics of the greywater. Without any specific information, the tank can be sized based on 7 hours of hydraulic residence time of the greywater design flow.

  Therefore, our design flow is 4.47 m^3/day,

  The volume of the tank can be calculated as shown below:

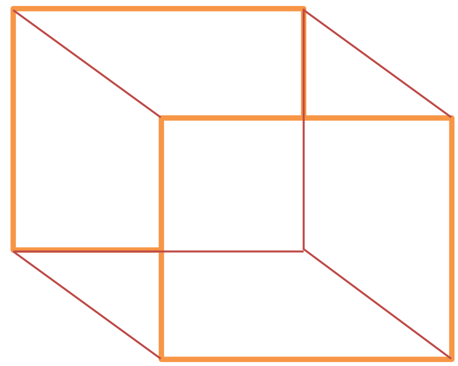
  7 hours x 1 day/24 hours x 4.47 m^3/day = **1.3 m^3**

Sludge tank dimension

L=1.25m

W=1.25m

H=1.25m



15 cm was added to each side as a safety precaution, as (Department, 2015)

Location and Access of Treatment Systems:

Treatment systems for greywater are likely to be located at ground level or below this apply to our design as well.

- Proper access for maintenance will ensure safe and efficient operation of the system. The treatment system will need periodic access to maintain pumps, change filters, and cleaning. Easy access around collection and treatment tanks should be provided, including sealed but not airtight man-sized access ports for all but the smallest tanks (e.g. 1 m^3 or smaller). This means our tank doesn't need one.
- Access to the treatment room(s) should be restricted and secured from public access for safety reasons.
- The tank should not be located directly above drainage pipes or other buried services.
- Should avoid the harsh mid-day sun light, therefor our thank should be located on the southern or northern part of the building.

Distribution from tank to the toilet:

- Distribution systems should be designed and constructed such that the overall storage time of reclaimed water does not result in unacceptable reduction in water quality. Header tanks for toilet flushing should not be oversized. Dead zones in the distribution piping should be avoided to prevent bacteria proliferation. For lengthy distribution systems, consideration should be given to recirculation of a small flow of the treated effluent to the treatment process to avoid stagnation

Distribution tank in our case should be around 1.5-1.7m^3 holding capacity

- There are no fundamental differences between the design of reclaimed water and mains water distribution systems, though the pipework and materials for the reclaimed water system should be chosen for resistance to corrosion.
- Care should be taken not to cross connect reclaimed water and mains water pipework during installation or subsequent work on the system. Pipe marking is essential to help avoid accidental cross-connection

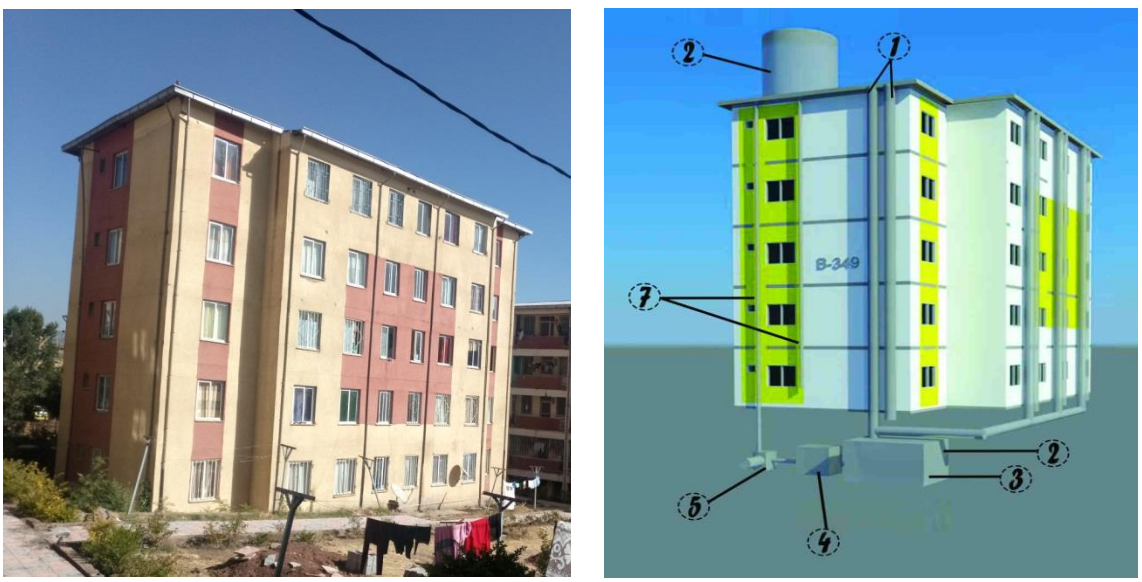


Figure 38: before and after picture of designed greywater system

5.2 Lab scale experiment of the four barrel treatment system

Materials that are used in this study were bought from s*hola gebeya* (around *megenagna, Addis Ababa*) and the material lists are mentioned in appendix-D, the hydraulic loading rate was 31 L/day with a retention time of 6 hrs and 7mm and 30mm gravel were used.

Step 1: buying the barrel, filter and gravel from the market

Figure 39: buying barrel from the market

Step 2: Drill the four barrels in the top right side assemble the fittings with the filter

Figure 40: assembling the barrels with fittings

Step 3: Set and install the four barrel with PVC and add the gravel 7mm gravel on the second barrel and 30mm gravel on the third barrel.

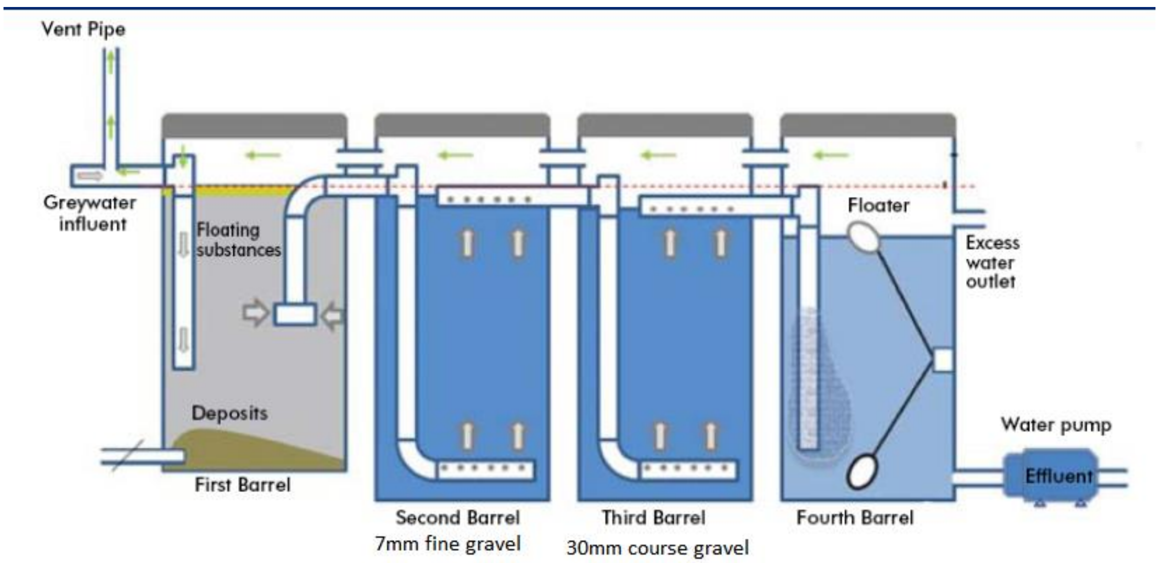


Figure 41: assembled are ready to go 4 barrel treatment system

Step 4: bring the greywater samples and characterize it before the treatment process

Figure 42: characterization before treatment

Step 5: start the treatment process according to the standards

This time two samples were brought from the site to the lab, and the treatment was conducted two times without changing anything, only two samples were conducted because of the financial and time constraints.

Step 6: test the characteristics of the treated greywater

Figure 43: characterization after treatment.

5.2.1 Lab Test Results of four-barrel Plastic Greywater Treatment Technology

The aim of this lab-scale study is to demonstrate the effluent quality of greywater reuse using a 4-barrel plastic greywater treatment technology for the quality parameters of BOD_5, TS, TSS, TDS, TVS, COD, DO in mg/l and PH values.

First sample: This sample was taken on a regular week day, in order to check the normal day quality of the greywater and what will be the effluent quality of the treated water quality.

Table 16: Greywater quality result after 4 barrel treatment of sample 1

No	Parameters	Unit	Sample1 (Influent)	Effluent
1	Biological oxygen demand(BOD_5)	mg/l	289.32	101.23
2	pH		7.91	6.9
3	Total solid(TS)	mg/l	1898	895
4	Total Suspended solid(TSS)	mg/l	211	98
5	Total dissolved solids(TDS)	mg/l	1778	797
6	Total volatile solids(TVS)	mg/l	1578	265
7	Dissolved oxygen(DO)	mg/l	3.4	2.1
8	Chemical Oxygen demand(COD)	mg/l	712	478
9	Microbial content	CFU	$2.68*10^4$	$3.12*10^4$

Second sample: This sample was taken on a weekend, because of a lot of cleaning up around the houses happen on the weekends, therefore checking the quality of the greywater on the weekend and studying the result was necessary.

Table 17: Greywater quality result after 4 barrel treatment of sample 2

No	Parameters	Unit	Sample2 (Influent)	Effluent
1	Biological oxygen demand(BOD_5)	mg/l	325.3	131.22
2	pH		8.22	7.21
3	Total solid(TS)	mg/l	2162	1001
4	Total Suspended solid(TSS)	mg/l	312	101.2
5	Total dissolved solids(TDS)	mg/l	1850	899.8
6	Total volatile solids(TVS)	mg/l	1858	302.02
7	Dissolved oxygen(DO)	mg/l	3.55	2.45
8	Chemical Oxygen demand(COD)	mg/l	748	481
9	Microbial content	CFU	$2.61*10^4$	$3.62*10^4$

As both samples demonstrated above fulfills the toilet flushing water standard(table 5) butt since the microbial content keep rising a use of disinfectant is recommended, in addition to that problem the odor and the color of the treated water was uncomfortable for the residents when showed the result. Then I come up with an idea which can solve the odour and color of the treated greywater, since installing a high tech treatment method is very expensive, we can use the low budget treatment method and get rid of the odor and color problem just by giving up a little tap water, my idea was redesigning how the toilet canister works.

Concept of the solution idea;

It was stated earlier in the design and the literature review that we use two separate plumbing in the canister when we use greywater recycling system, one for the treated greywater and the other for the tap water which will come handy when there is a shortage in treated greywater or malfunction in the treatment system. Therefore since we have the direct tap water plumbing in the canister, we can use that to our advantage and get rid of the smell and odor of the treated greywater by giving up a little water and redesigning the toilet canister.

Here is a typical toilet canister which uses 6-8 liters of water per one flash,

Figure 44: typical condominium toilet seat and canister

Weather it use greywater or tap water, the 8 liters are used to remove the human waste from the toilet bowl, my idea is to use both waters at the same time but in different volumes. That means out of the 6 liters of water a canister releases in one flush, 5 liters of it will the treated greywater which will do all the dirty of removing the human waste from the bowl and 1 liter of clean tap water will also be flashed automatically to wash the bowl, which will remove the greywater used to flush the toilet and the odor of the bowl and the color of the water in the bowl will be just like a normal toilet which uses tap water only.

Figure 45: Partitioned toilet canister.

Chapter 6

6. Conclusion and Recommendation

6.1 Conclusions

This thesis assessed a feasible way to help mitigate the huge shortage of water in Addis Ababa specifically in condominiums by taking a sample condominium block from *"summit condo"* located in bole sub city. If the city continues evolving the same way it did over the past 10 years the living standards and the population number will be expected to grow in a dramatic rate, which will bring more challenges for Addis Ababa's water supply and demand balance.

As a result Addis Ababa water and sewerage authority need to consider more options for water supply or preservation in order to fulfill the current and the future demand rather than spending resources finding new small ground water wells. This study shows there is a possibility of decreasing the total potable water demand up to 30% by considering greywater reuse. Adopting such system will benefit both the consumer and the provider in many ways.

According to the result of this study Membrane bio-reactors (MBR) and PGTS treatment technologies were the best methods to implement in condominiums considering many factors and the system can support and contributes to minimize the gap between the water supply for the existing and future water demand of the city.

6.2 Recommendations

As observed in the study, greywater recycling system have the potential to substitute the toilet flushing water which can sum up and save almost 30% of the total water demand in the city. Therefore the researcher recommends the following point based on the study to make such a system a reality in the city.

- Separation of greywater and blackwater in the existing condominiums should be done by separate plumbing
- Since there are around 80% of low income housing which are yet to be built, considering the integration of greywater system in the buildings before the building of the houses can save a lot of resource, time and will be much convenient to implement than the existing condominiums.
- AAWSA should study the potential of reusing greywater for toilet and develop a framework, so that people can easily design and integrate greywater recycling systems on existing or future buildings.
- Educating people on the benefits of reusing greywater should be given a big consideration before implementing such system.
- Addis Ababa water and sewerage authority and Addis Ababa housing construction project office should work together to design an efficient water and sanitation plan which will consider greywater reuse as a part of the design.
- MBR and different PGTS methods should be studied in detail and should be implemented in the condominiums as a pilot study before designing a constant method of reuse.
- Use of disinfectant is also recommended for PGTS(4-barrel in our case) methods
- One of PGTS methods (The 4-barrel greywater treatment technology) requires substantial cases study on size, media, and disinfection method in order to find the maximum effectiveness, because the 4 barrel system is highly affected by the amount of greywater to be treated and variable quality of greywater.
- The cost analysis of the redesigning and the implementation of a two source toilet canister should also be studied.

REFERENCES

A. A. ILEMOBADE, O. O. (2012). *Greywater reuse for toilet flushing.* durban: water research commission of south africa.

AAHCPO. (2015). *Report on condominium housing.* Addis Ababa.

AAWSA. (2019). *budget year Addis Ababa water supply and distribution report.* Addis Ababa.

Admasie, A. M. (2015). *ASSESSMENT OF THE WATER DEMAND MANAGEMENT OF CONDOMINIUM HOUSES CONSIDERING GREYWATER REUSE.* Addis Ababa.

Agency, E. M. (2018). *final repot on Addis Ababa weather status.* Addis Ababa.

Al-Jayyousi, O. (2003). *Greywater reuse: towards sustainable water management.*

Asano, T. (1998). *Wastewater reclamation and reuse.* Panama: Lancaster.

Burnat, J. M. (2005). *Evaluation of on-site gray wastewatertreatment plants performance in Bilien and Biet-Diko villages/Palestine.* Environment Protection Committee (EPC).

Butler, D. (1991). A small scale study of wastewater discharges from domestic. *Journal of International Water and Environmental Management*.

Central Statistical Agency, C. (2010). *Population Projections for Ethiopia.* Addis Ababa.

Chin-Jung, L. S.-L.-Y.-H. (2005). Pilot-Scale Electrocoagulation with Bipolar Aluminum Electrodes for On-Site Domestic Greywater Reuse. *Journal of Environmental Engineering*, 131.

Christova-Boal, D. E. (1996). *An Investigation into Greywater.*

CSBE, C. f. (2003). *Greywater reuse in other.* Jordan.

D, S. S. (1998). *Greywater reclamation for non-potable reuse.* J. CIWEM.

D, S. S. (1998). *Greywater reclamation for non-potable reuse.* J. CIWEM.

Dallas, S. S. (2004). *Reedbeds for greywater treatment – Case study in Santa Elena-Monteverde.* Ecological Engineering: Costa Rica, Central America.

Del Porto, D. a. (2000). *What about Greywater, The composting toilet system book. Massachusetts the Center for Ecological Pollution Prevention (CEPP).* Concord, Massachusetts.

Department, U. S. (2015). *TECHNICAL SPECIFICATIONS ON GREYWATER REUSE AND RAIN WATER HARVESTNG.* Chicago: 1st Edition.

dickon, j. (n.d.).

Duncan, B. G. (2002). *http://www.geocities.com/bwduncan/caids02.html*. Retrieved from http://www.geocities.com/bwduncan/caids02.html.

E, N. (1999). *Greywater reuse systems for toilet flushing in multi-storey buildings over 10 years experiance in Berlin.* Berlin, Germany.

El Hamouri, B. N. (2207). *Subsurface-horizontal flow constructed wetland for sewage treatment under Moroccan climate conditions.* Morroco.

Eriksson, E. K. (2002). *Characteristics of grey wastewater.* Urban Water.

Eriksson, E. K. (2002). *Characteristics of grey wastewater Urban Water.*

Eriksson, E. K. (2002). *Characteristics of grey wastewater.* London.

FAO, F. a. (1985). *Water quality for agriculture. Irrigation and Drainage.* Rome.

Febri, A. (2005). *Greywater Treatment on Household Level in Developing Countries.* Zurich.

Friedler, E. (2002). *Quality of individual domestic greywater streams and its implication.*

Friedler, E. (2004). *Quality of individual domestic greywater streams and its implication.* Environmental Technology.

G.augest, M. (2014). *Journal of Environment Pollution and Human Health*, 58-62.

Ghisi, E. a. (2007). *Potential for portable water savings by using rainwater and greywater in muiti-storey residential buildings in Southern Brazil.* Rio, Brazil.

Gill, P. S. (2008). *Methods of data collection in qualitative research: interviews and focus groups.* Br Dent J.

Griggs, J. P. (1997). *Water conservation: A guide for design of low-flush WCs. Building Research Establishment Information Paper.*

Gross, A. W.-S. (2006). *Reliability of small commercial greywater treatment systems.* Grece.

Hills, S. S. (2201). *Water recycling and the Millennium Dome.* London, UK: Water Science and Technology.

Holt, P. a. (2003). *Wastewater reuse in the Urban Environment: selectionof technologies. Landcom's WSUD strategy*. Retrieved from http://www.arc.agric.za/institutes/infruit/main/divisions/resourcepoor/research.htm

Jefferson, B. J. (2001). *Treatment methods for greywater.Decentralised Sanitation and Reuse. Concepts, systems and implementation.* Ed. Lens.

Laak, R. 1. (1998). *Manual of Greywater Treatment Practice.* Michigan: Ann Arbour Science.

Laine, A. T. (2001). *Technologies for greywater recycling in buildings.* Cranfield University, UK.: PhD Thesis.

Lazarova, V. (2001). *Role of water reuse in enhancing integrated water management in Europe Final report of the EU project CatchWater.* Paris, France: ONDEO.

Li, F. W. (2009). *Review of the technological approaches for greywater treatment and reuses.* Science of The Total Environment.

Ligman, K. H. (1974). Household WastewaterCharacterization. *ASCE Journal of the Environmental Engineering Division*, 204.

Lin, C. J. (2005). *bipolaraluminium electrodes for on-site domestic greywater.*

March, J. G. (2002). *Experiences on greywater re-use for toilet.* Mallorca Island, Spain.

Mikkelsen, P. S. (1999). *Collected rainfallas a water source in Danish households – What is the potential and what are the costs?* Water Science and Technology.

Oasis Design, A. G. (2006). *http://www.oasisdesign.net*. Retrieved from http://www.oasisdesign.net: http://www.oasisdesign.net/greywater/law/arizona/index.htm. assessed 23 Nov

Ottoson, J. a. (2003). *2003Faecal contamination of greywater and associated microbial risks.* Water Research.

PPSA, P. P. (2013). *Socio-Economic Profile of Addis Ababa, Ethiopia.* Addis Ababa.

Program, E. G. (2015). *Greywater recycling and reuse.* Cairo.

Sayers, D. (1998). *A Study of Domestic Greywater Recycling.* Worthing, West Sussex, UK.: National Water Demand.

Siegrist, R. W. (1976). The characteristics of rural household wastewater. *Journal of the Environmental Engineering Division,* 533-538.

Stanner, D. a. (1995). *Europes Environment: the Dobris assessment European Environment Agency Task Force (European Commission: DG XI and Phare), Luxembourg: Office for Official Publicaitons of the European Communities.* Paris.

Steven E. Williams, P. (2011). *Reconsidering Rotating Biological Contactors as an Option for Municipal Wastewater Treatment.* New York.

Tchobanoglous, G. (1991). *Wastewater Engineering, Treatment, Disposal, and Reuse.*

UN-HABITAT. (2018). *Water and sanitation in the world's cities: Local action for global goals:*. Earth scan publication.

USEPA, U. S. (2007). *Code of Practice Wastewater Treatment Systems for Single Houses.*

Van der Hoek, J. P. (1999). The use of Biological Activated Carbon Filtration for the removal of natural organic matter and organic micropollutants from Water. *Water Science and Technology*, pp. 257-264.

WHO, W. H. (2006). *Guidelines for the safe use of wastewater excreta and greywater Volume 2. Wastewater use in agriculture.* Geneva,Switzerland.

Appendices

Appendix A: Questionnaires

Part I: General Information

House number_____________

1. Sex

Male ☐ female ☐

2. Age

Below 18 ☐ 18-35 ☐

35-55 ☐ above 55 ☐

3. Marital Status

Married ☐ Divorced ☐

Single ☐ Widowed ☐

4. Educational level

Illiterate ☐ Can read and write (1-8) ☐

9-12 diploma ☐ Degree and above ☐

5. Income

Less than 2000 birr/month ☐ 2000-5000 birr/month ☐

5000-10,000 birr/month ☐ Above 10,000 birr/mont ☐

6. How many people live in your house? ____________

7. How often do you wash cloths?__________

8. What type of mechanism do you use to wash cloths?

Hand ☐ Washing Machine ☐

9. If you are using hand, how many buckets of water do you use for one washing session?________

10. If you are using washing machine,

What Kg/Liter is the capacity of your washing machine? _______

11. How many times do you fill the water in your washing machine in one session of washing? _______

12.Where are you spill out the wastes from cloth washing?
In the toilet ☐ In the shower or hand sink ☐ Outside the house ☐
Other_____

13. How often do you take a shower?

Daily ☐ Twice in a week ☐

Once in two weeks ☐ Other____________

14. How much water do you use in the kitchen per day? ______ Liters or ______ Buckets

15. How much water do you drink per day?_____ liters or ______Glass

16. Do you use anything else besides soap and conditioner in the shower? N ☐

Y ☐ If yes, mention____________

17. How often do you use the toilet (including urine use) on average? ________

18. What are the other options you use during the absence of water?
Using the bite save water ☐ Buying Water from other plac ☐

Both of them ☐ other ______________

Part II- Perception/ Opinion
1. How bad is the water shortage in your condo?

Very bad ☐ Bad ☐

It is not that bad ☐ It's actually good ☐

2. Have you ever heard or know about Greywater recycling?

Yes ☐ No ☐

3. How do you express the lack of water in your toilet on daily bases?

I have no problem on that ☐ I can manage it by buying water ☐

It is very difficult ☐ Other_____________

4. Would you be comfortable if greywater from your house recycled back to your toilet?

I strongly disagree ☐ I disagree ☐

I agree ☐ I strongly agree ☐

5. How do you express the current price of water?

Very Expensive ☐ Expensive ☐

Moderate ☐ Cheap ☐

6.How do you express the price of water? (The water you buy when there is no tap water)

Very Expensive ☐ Expensive ☐

Moderate ☐ Cheap ☐

7. Will you be fine if the existing plumbing installation change, which will include the reconstruction inside your house?

Yes ☐ Yes if I am not paying ☐ Not at all ☐

8 How would you describe yourself regarding water use?

Wasteful ☐ Normal ☐ Conservative ☐

Appendix B: Questionnaire for Interview with experts

The purpose of this questionnaire is to develop a Framework for evaluating greywater treatment methods for toilet flushing in mass condominium housing site located in Addis Ababa City.

All information gathered from this questionnaire will be used for academic purposes. Furthermore, it will remain anonymous, treated confidentially and I will be destroying after the production of the final results. Thank you for taking time to answer the questionnaire.

Please read the questions carefully and answer as honestly as you can on the space provided.

1. Do you think there is sufficient water supply for condominium houses? Why?

2. What are the advantages and disadvantages of greywater recycling for toilet reuse purpose?

3. Do you think there will be a positive public opinion for the acceptance of greywater recycling? why?

____
____
____
____
____
____
____

4. Is there any installed greywater treatment technology for the purpose of toilet flushing that you know? Where? ____

5. Which one of the following consideration you think is very important for the selection of greywater technologies? Please give a rating ranging from 0-10

(0=not necessary to consider 10= very necessary to consider)

A. Land space required for construction _______
B. Quality of the treated greywater ________
C. Odor of the treated greywater _________
D. Color of the treated greywater_________
E. Relative investment and running costs __________
F. Personnel skills required _____________
G. Availability of the technology in the city ___________

___ ___ ___ ___ ___ ___ ___ ___ ___ ___ ___ ___ ___ ___ ___

Experts which are going to be involved in this questionnaire are University teachers and researchers in the area of Environment and Water Engineering, experts working in designing and planning department of AAWSA, AACHPO,EPA (Ethiopia) and selected residents at the case study area.

Appendix C: English Questionnaire Translation to Amharic Questionnaire

በመጀመሪያ ጊዜዎን ሰውተው መጠይቁን ሇመሙሊት ፈቃዯኛ ስሇሆኑ በጣም አመሰግናሇሁ፡፡ስሜ አስማማው መኮንን እባሊሇሁ፡፡በ አዲስ አበባ ዩኒቨረሲቲ በሲቪሌ የምህድስና ትምህርት ክፍሌ የማስተርስ ተማሪ ነኝ፡፡ይህንን መጠይቅ ያዘጋጀሁት በሚኪሉ ሊንድ የጋራ መኖሪያ ቤቶች የሚኖሩ ነዋሪዎችን የውሃ አቅርቦትን መሌሶ ከመጠቀም አኳያ ያሊቸውን አመሇካከት እና ግንዛቤ ምርምር ሇማካሄድ እና ሇማጥናት ነው፡፡ይህንን መጠይቅ ሲሞለ ከማንኛውም የፖሇቲካ ጉዳዮች የፀዳ እና ሇምርምር አገሌግልት ብቻ የሚውሌ መሆኑን በመረዳት መጠይቆችን ያሇምንም ፍርሀት የራስዎን መሌስ በትክክሌ በማክበብ እንዲመሌሱ በአክብሮት እየጠየኩኝ የሚሞሇት መጠይቅም ከሪፖርት በኋሊ የሚወገድ መሆኑን ሇመግሇጽ እወዳሇሁ፡፡

1. አድራሻ_________________________የብልክ ቁጥር___________________________

2. ፆታ

   ሀ. ወንድ ሇ. ሴት

3. ዕድሜ

   ሀ. <18 ሇ. 18-35 ሐ. 35-55 መ. ከ 55 በሊይ

4. የቤተሰብ ብዛት_______________________________________

5. የትምህርት ዯረጃ

   ሀ. ከ 1ኛ ክፍሌ በታች ሇ. ከ1ኛ-8ኛ ክፍሌ ሐ.10ኛ -ዲፕልማ መ. ዲግሪ እና ከዚያ በሊይ

6. ወራዊ ገቢዎ ስንት ነው?

   ሀ. ከ 2000 በታች ሇ. ከ 2001-5000 ሐ. 5001-10,000 መ.ከ 10,000 በሊይ

7. በሚኖሩበት አካባቢ የውሃ ችግር አሇ ወይ?

   ሀ. አዎ ሇ. አሌፎ አሌፎ ሐ. የሇም

8. ውሃ በማይኖርበት ጊዜ ውሃ የሚያቆይ የውሃ ማጠራቀሚያ አሇዎት?

   ሀ. አዎ ሇ. የሇም

9. ውሃ በማይኖርበት ወቅት ውሃ ሇማግኘት የሚጠቀሙበት አማራጮች ምን ምን ናቸው?

   ሀ.ያጠረቀምኩትን ውሃ እጠቀማሇሁ ሇ.ውሃ ካሇበት አካባቢ ውሃ በመግዛት እጠቀማሇሁ

   ሐ.ሁሇቱን ዘዴዎች እጠቀማሇሁ መ.ላሊ ካሇ ይግሇጹ

10. በወር የሚከፍለት የውሃ ክፍያ ውድ ነው ብሇው ያምናለ?

    ሀ. አዎ ውድ ነው ሇ. ርካሽ ነው

11. በወር የሚከፍለት የውሃ ክፍያ ምን ያህሌ ነው?

    ሀ. ከ16.17 ብር በታች ሇ. ከ20.77-75.95ብር ሐ. ከ81.69-190.90 ብር መ. ከ198.10-622.87 ብር ሠ. ከ631.88-2425.77 ረ.ከ2425.77 በሊይ

12. ሌብስዎን የሚያጥቡባቸው ዘዴዎች ምን ምን ናቸው?

ሀ.የሌብስ ማሽን በመጠቀም ሆ. በሳፋ እና በሰፋፊ ባሌዲ በመጠቀም ሐ.ሳልች ካለ ይግሆጹ

13. ሌብስዎን ካጠቡ በኋሊ ያጠቡበትን ውሃ ወዯ የት ያስወግዳለ?

ሀ. ወዯ ሽንት ቤት ሆ. ወዯ ሻወር ቤት ሐ. ወዯ መንገድ ዲች /ዳር/ መ.ሳልች ካለ ይግሆጹ

14. ገሊዎን፤እጅዎን እና ሌብስዎን ከታጠቡ በኋሊ የታጠቡበትን ውሃ በቤትዎ ውስጥ በአነስተኛ ቴክኖልጂ ተጣርቶ ቢቀርብሆዎት ሆሚፈሌጉት አገሌግልት መጠቀም ይችሊለ?

ሀ. አዎ ሆ. መጠቀም አሌችሌም

18. ከገሊዎ፣ ከእጅዎ እና ከሌብስዎ የሚወጣውን ውሃ መሌሰው በመጠቀምዎ የውሃ ችግርዎንና ሆውሃ የሚያወጡትን ክፍያ እንዯሚቀንስ ያውቃለ?

ሀ. አውቃሆሁ ሆ. አሊውቅም

19. ከውሃ አጠቃቀም አኳያ ራስዎን እንዴት ይገሌጹታሌ?

ሀ. ውሃን አባክናሆሁኝ ሆ.ውሃን በአግባቡ እጠቀማሆሁኝ ሐ. ውሃን በቁጠባ እጠቀማሆሁኝ

Appendix D: materials used in order to build the 4 barrel lab-scale

No	Materials	Unit	Size	Quantity	Cost(ETB)	Total cost(ETB)
1	Barrel plastic	Liters	40	4	200	800
2	Sand	N/A	Spade	6	15	90
3	Grave	N/A	6	6	20	120
4	PVC	Inch	1	1	240	240
5	Faucet	Inch	1	1	30	30
6	Fiber	Pc	1	1	10	10
7	Coupling	Inch	1	1	10	10
8	Connector	Inch	1	6	10	60
9	Union	Inch	1	6	60	360
10	Filter	Pc	1	1	120	120
					Total cost	1840